"In presenting the dissertation as a partial fulfillment of the requirements for an advanced degree from the Georgia Institute of Technology, I agree that the Library of the Institution shall make it available for inspection and circulation in accordance with its regulations governing materials of this type. I agree that permission to copy from, or to publish from, this dissertation may be granted by the professor under whose direction it was written, or, in his absence, by the dean of the Graduate Division when such copying or publication is solely for scholarly purposes and does not involve potential financial gain. It is understood that any copying from, or publication of, this dissertation which involves potential financial gain will not be allowed without written permission.

AN EVALUATION OF A TIME STUDY TRAINING
DEVICE BASED ON TACHISTOSCOPIC PRINCIPLES

A THESIS

Presented to

the Faculty of the Graduate Division

by

Arthur Bruckner, II

In Partial Fulfillment

of the Requirements for the Degree

Master of Science in Industrial Engineering

Georgia Institute of Technology

April, 1958

AN EVALUATION OF A TIME STUDY TRAINING

DEVICE BASED ON TACHISTOSCOPIC PRINCIPLES 5A 12T

APPROVED:

Date Signed by Chairman: May 30, 1958

ACKNOWLEDGEMENTS

Without the cooperation and efforts of many people, the successful completion of this thesis would have been impossible. I would like to mention first my appreciation to the industrial engineering students at West Virginia University for their amicable participation. Mr. James J. Vasoti deserves special mention for his yeoman service in the micromotion studies and abstract work.

I am further indebted to all of the faculty of the School of Industrial Engineering at the Georgia Institute of Technology for their friendly assistance and consideration during my graduate studies and thesis preparation. The example of Director F. F. Groseclose has given me a personal goal of engineering ethics and human relations to follow.

In the forefront is my appreciation of the labors of my thesis advisors. Remembered are the personal guidance of Dr. R. T. Staton, Jr., and his services as chairman of my thesis committee; the patient statistical help of Dr. J. J. Moder, Jr.; and the encouraging counsel about thesis preparation of Dr. K. M. Murphy. They have set an example of conscientious educators.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

SUMMARY

The purpose of this research was the evaluation of a time study training device based on tachistoscopic principles. The objectives of this device were: (1) to develop a useful proficiency level of reading a time study stopwatch in less time than customarily required, or an increased proficiency for the same training time; (2) to reduce the number of missed observations; and (3) to develop principles of technique which could be retained by the student for any later period. A broader objective was the hope that such training would improve the student's confidence.

Literature review indicated that other areas had achieved considerable success in speed and comprehension of observation from tachistoscopic training. A mechanically operated shutter device was then designed, with its face a model of a decimal-minute stopwatch.

The assumption was made in the experimental design that a laboratory period of three hours represented the usual college training time allotted for introduction to use of the stopwatch. The experiment consisted of three stages of training for tachistoscopically and classically trained groups, each consisting of thirteen subjects. The first stage was technical instruction with combined groups. In the second stage each group received respective training.

The third stage combined both groups for the data-taking session of timing an assembly operation. The measurement control used in this stage was micromotion filming.

Three quantitative measures were used to evaluate the third stage data of the two groups. These measures were: bias, the measure of accuracy; timing variation, the measure of precision; and the percentage of missed observations. Bias was evaluated as:

$$\text{Bias}_{\text{subject}} = \overline{X}_{\text{recorded total}} - \overline{X}_{\text{micromotion control}}.$$

Based on the realization that times recorded by the subject included both subject variation and operation variation, this expression was used:

$$\sigma^2_{\text{subject}} = \sigma^2_{\text{total}} - \sigma^2_{\text{operation}}.$$

The micromotion control measured only operation variation. A chi-square test was used to evaluate the difference between the methods of the percentages of missed observations.

A factorial design of a mixed model nature with one classification nested was used to interpret the bias and timing variation data. The main effects were training methods (M), time study elements (E), and subjects (S) nested in methods. The mathematical model used to describe this experiment was:

$$x_{ijk} = \mu + S_{i(j)} + M_j + E_k + ME_{jk} + \epsilon_{ijk}.$$

Based on the results of the statistical analyses and within experimental limitations, the conclusion reached was that for each quantitative measure the classical training method is significantly better. However, the relative magnitudes of differences between methods indicate that they are reasonably equivalent, and that the time parameters chosen may be too strict. Retention qualities were indeterminable from this experiment. The quality of the training device and its exposure times were questioned.

It is recommended that further investigations be made into refined devices and training procedures, because of the desirable objectives to be attained in this field and related fields where speed and accuracy of dial or multi-dial observations are important. It is also recommended that investigations be made into the possible existence of theoretical relationships between tachistoscopic principles and the information theory.

CHAPTER I

INTRODUCTION

Purpose and background study.--The primary purpose of this research is the evaluation of a mechanical training device to determine its ability to increase the manual proficiency of reading a time study stopwatch in initial undergraduate training.

The objectives of this device are:

1. To develop the ability of inexperienced students in reading the stopwatch.
2. To attain a useful proficiency level of ability in a period shorter than commonly required, or an increased proficiency in the same period.
3. To reduce the number of missed readings in time study observations.
4. To establish principles of technique which the student can retain.
5. To stimulate the individual student's confidence in his own ability.

All of these are important factors in class instruction in motion and time study. However, a little effort has been made to solve these problems by improvement of training techniques.

The above statement should not be construed to mean that these are the most important problems in motion and time study instruction. They are not. Instruction in the increasingly technological procedures is the purpose of the course, but it is necessary and pertinent in such courses that training be given in the manual use of the stopwatch. This training is necessary for course project analysis work; to achieve successful application of such project analyses it is necessary that enough skill be developed to obtain qualified data by the individual student for analysis and evaluation. Industry also expects a proficiency great enough that only moderate additional practice is necessary for the graduate engineer to participate actively in the productive work of setting time standards and accumulating manufacturing data.

Problems of industrial relations cause the need of a reasonably high ratio of "made" readings to readings missed during time studies before the establishment of worker performance standards. Labor tends to oppose establishment of such standards in cases where the original observation sheets show a high percentage of missed readings. This opposition is caused by the belief that only readings favorable to management might be used to establish performance standards. Erroneous as this view of professional ethics may be, there is some statistical strength to this argument since missed readings may reflect "high times" necessary to job performance on a periodic or random basis.

All of these problems cause conflicts in plans of training. These conflicts are often resolved by one of two approaches: (1) too much stopwatch training so that the technical perspective of motion and time study is under-emphasized; (2) too little training, from which may result, in course project work, insufficient preparation and unrealistic data. The present increases in the course content of motion and time study classes preclude the lengthy use of laboratory periods devoted to stopwatch practice only; the laboratory periods have much more vital training work to be covered. Hence, it is necessary to develop the ability to read a stopwatch in a minimum of laboratory time.

Therefore, it seems that although stopwatch training is not college-level technical training, it is the responsibility of such courses to prepare adequately their students in this skill. Even more, the student will gain no realistic appreciation of applied course material without the achievement of a level of skill high enough that he can gather data for engineering usage. The student's data need to be realistic if he is to achieve a sound sense of proportion.

Equally important, though less tangible, is the development of the student's confidence in his skill and ability, coupled with development of his perspective of the relative role of the stopwatch in motion and time study.

A substantially large percentage of industrial engineering students lose interest and refuse professional positions in work requiring time study. This situation is caused both by a false perspective of such work and a lack of confidence in their stopwatch-timing ability. This is an unfortunate situation for the profession, as its growth is partly dependent on the caliber of men that can be attracted to this foundation area, where development to positions of manufacturing responsibility can well occur, and where in turn can be nurtured the wider adoption of industrial engineering practices. These stated attitudes of students range from "my data will never be accurate enough" and "I'll never get the knack of it for small element jobs" to "I don't want a methods engineering job because all one will do is take time studies". These attitudes are believed to be largely caused by a lack of confidence.

It is hoped that better training procedures--not just a larger amount of time--will aid in developing confidence. Further, a planned program of training with principles of technique behind it could cause enough retention of material that later use of the stopwatch will cause him to recall a stopwatch-reading technique. Such a program is better than merely giving the student the idea that the stopwatch observer needs long periods of practice. Knowledge of principles will develop a more easily recalled skill than sporadic practice offers.

Additionally, data will be obtained concerning the *initial performance* levels of inexperienced industrial engineering students' time studies.

Origination of the problem.--In the spring of 1956, a large group was to receive time study training in both snapback and continuous methods of observation timing. The size of the group prohibited close observation of the individual student by the instructor during the practice sessions. During this same period, a senior seminar group needed a project. A series of discussions were held in this seminar on the subject of training procedures. The possibilities of a mock-up or model of a stopwatch were discussed. However, the interpretation of the stopwatch scale is elementary and it is felt that little or no advantage would be gained by such a device. What was needed was training in reading a stopwatch under normal conditions, and not scale reading under stationary conditions. The discussion was then led into types of military training and then aircraft recognition techniques were discussed. Comparisons were made to the present techniques used in courses in reading skills.

From this discussion, the idea of a stopwatch face model with a turnable but non-moving hand behind a spring-loaded shutter was evolved as analogous to the above training procedures. Such a device was then developed and used to train the large group for one class period two days prior to the first time study session.

The time study session used the snapback method of observation and lasted for one class period. The operation times was the assembly of a small part with the time study elements ranging from 0.05 to 0.10 minute. The subjects used standard decimal-minute stopwatches.

Intuitively, the results were felt to be outstandingly good. Intuition was aided by noticing virtually simultaneous "clicks" resulting from the snapback recording method and the low (approximately ten per cent) percentage of misses to total elements performed by the operator assembling the small part.

It was then decided that this procedure would be worth investigation on two possibilities. The first was the development of better proficiency and/or less training time needed for a reasonable level of proficiency. The second was the establishment of a definite procedure in the place of the common present use of practice alone with technique individually developed by trial and error procedures.

<ins>Summary</ins>.--Following establishment of a successful training procedure, it could be taught, and as such, could be retained in principle for use by all students at any later date when it became necessary in the engineering routine to gather some form of manufacturing performance data. It might be well to point out that industrial engineering often calls for little time study itself, except when information is

needed for some particular project; hence, practice skills cannot be maintained.

An effort should be made to develop improved training procedures in order to gain both improved ability and reduction of the time required for such training, whereas presently too little effort has been made. Time study training is necessary for industry and course project work.

More critical, though seemingly trivial, is the problem of lack of confidence which has often caused the rejection of time and methods study work by the prospective industrial engineer.

Analysis of the experiment will determine quantitatively the capabilities of the training device to meet these objectives.

CHAPTER II

SURVEY OF RELATED APPLICATIONS LITERATURE

Introduction.--Literature investigation of training devices in aircraft recognition training and reading improvement training indicated that the newly designed device was directly parallel in principle to tachistoscopic equipment. Tachistoscopic devices are currently used in two major areas: (1) experimental psychology research, and (2) educational work in improving reading rates and comprehension.

The tachistoscope is a devicebasically similar to a camera shutter. In the case of the tachistoscope, a timed exposure of information is portrayed on a screen with controlled illumination intensity.

> "A tachistoscope is an apparatus which exposes to view an object, a group of letters, words, *et cetera*, for a selected brief period of time. . . ." In its most practical form for classroom use, the tachistoscope consists of: (1) a means of showing targets to an entire class at one time, (2) a timing device for exposing the targets, and (3) targets suitable for the subject being taught (1)[1].

---

[1]This number and following numbers in parentheses refer to references cited in the Bibliography.

Psychological background.--The earliest uses of the tachistoscope resulted from the needs of experimental psychology in evaluations of eye span ability and time needed for visual stimulation. Experimental usage of the tachistoscope in reading work goes back to 1885 with the pioneer work of Cattell (2). Even earlier applications were made in experimental work by Hamilton and Jevons concerning problems of the span of attention (3). It was not until the 1930's that Rusk suggested that modified equipment could be used for group training. Applications of the tachistoscope in group training work were not made until as late as 1938 and 1940 when it was first applied to reading and spelling training in Pennsylvanian and Californian secondary school classrooms (4). Experimental psychology has made considerable use of the tachistoscope for research concerning the visual perception of form, and its factors of figure versus ground. This has been coupled with investigations of optical physiological effects and problems of afterimages. The tachistoscope is important in experimental research, because it can control the time of the visual stimulus.

> First developed for the purpose of discovering how brief a stimulus could arouse visual sensation, it was adapted by Cattell for use in span and reading experiments. Here the fundamental requirements is to allow only one glance; the eyes must not have time to change their fixation point during the exposure (5).

For experimental applications, it is recommended that the pre-exposure field to be observed have the same light intensity that the figure to be observed will have when portrayed. A fixation point for viewing should be established prior to flashing the figure; a tachistoscope is sometimes called a flashmeter. It is also important that the post-exposure field light intensity be controlled for problems of afterimages caused by a lag in the retina. The time of exposure has to be long enough to let the operator make a fixation, but he should be limited by the exposure time from making two fixations. The controlling time is determined by the reaction time needed by the eyes to shift to another fixation point. The upper limit is as high as two hundred milliseconds (6).

Physiological factors.--During reading, the saccadic or travel movements of the eyes occupy only a small fraction of the total reading time. Improvement in reading speed and comprehension is accomplished by increasing the span of attention or apprehension so that both less fixations are needed and the time per fixation is decreased (7). In slow reading the fixation time may be as high as ninety-five per cent of the total reading time percentagewise, fast readers spend a smaller amount of time on fixations and more time on saccadic movements. However, fixation time in normal reading includes the time of perception and recognition and is necessarily increased by the time for integration of sensory effects by the brain to comprehend the meaning. In reading, the first fixation is usually the longest, as peripheral vision causes some preliminary examination of subsequent material. This is important since reading a time study stopwatch requires isolated single fixations interrupted by observation of the job. Further, the eyes are operating under the environmental condition of looking at a moving dial hand. Distinct vision and evaluation of an object by the eyes is only possible when the retina views the object in a stationary position. If the eye is to observe a moving object, it must use a pursuit motion to follow the object at its pace in order to make it stationary by relative motion. At the best, only a blurred vision results from saccadic movements. A relatively fixed motion or fixed object is necessary for clear vision fixations (8).

Distinct, sharply identified vision is a physiological function of the fovea, that part of the retina consisting of photosensitive cone cells. They are located at the center of the retina and comprise only a two degree arc of the retinal surface area. The inherent, subconscious reflex action of humans under normal lighting conditions is the exclusive use of this area by moving the eyes so that the image falls on the fovea. This type of eye fixation is called photopic vision, and is of relative physiological importance since the normal sized stopwatch dial figures require distinct vision fixation for accurate interpretation. Broadening the perceptual scope of vision requires training in using the rod cells in combination with cone cells, mesopic vision (9).

<u>Introduction to training applications</u>.--The first tachistoscopic training program was a result of a wartime emergency; pilots were shooting at their own side's planes. Because of the speed of air travel, the airman had his time available for recognition sharply reduced; hence, identification was often erroneous. For example, sixty of the ninety-two planes lost at Dieppe were shot down by their own anti-aircraft guns; Italian planes even sunk their own cruisers. Before this tachistoscopic training, the standard practice of recognition was factor-by-factor identification. For example, a plane would be identified step-by-step as to its characteristics of wing outline, fuselage, tail structure, and engines. This was called the "WEFT" system. Similar training was used in other military identification problems. From the prior discussion, it is evident that a considerable number of fixations and brain integrations were necessary to ascertain whether the visual contact was with friend or foe. However, the relative speeds of military equipment in World War II did not allow the amount of time required for positive identification.

The first training program using tachistoscopic principles was initiated and sponsored by the Navy Bureau of Medicine and Surgery in 1942. The program was developed and initially led by Dr. Samuel Renshaw, Department of Psychology, College of Education, Ohio State University. The first military trainees showed improvements from original levels of twenty per cent accuracy to after-training levels of ninety-eight per cent accuracy in one-quarter of the prior recognition time of one twenty-fifth of a second. This training ultimately spread to the American armed services, as well as those of the British Commonwealth. As many as 285,000 pre-flight cadets were so trained. The field results proved the worth of this training which Renshaw had modified from individual to group training (10). The military training program had three fundamental objectives: "(1) to improve general vision effectiveness, (2) to train the observer to accurately estimate the number of objects in the field of vision, (3) to train the observer to instantly recognize aircraft, surface vessels, and armored land vehicles" (11).

Since the war impetus, this training has widely spread to school and special training programs. Most reading skill courses have made use of tachistoscopic equipment and procedures, such as those of Pittsburgh University. The tachistoscope is often used in conjunction with other equipment in these programs. For example, in the training of fifty-six engineers at Battelle Institute results were reported of an increase to 313 words per minute versus the old average reading speed of 262. Moreover, the comprehension increased from fifty-two to eighty-five per cent. These training programs have shown similar gains at other types of activity. Widespread grammar school programs have also reported outstanding gains in reading speed and comprehension from using tachistoscopic training. Highly successful applications, as compared to old performance levels, have been made in many varied fields. Some of these additional applications are: training of handicapped students; music training at Stephens College; secondary school spelling and arithmetic; foreign languages; adult programs for special purposes, such as executive and bookkeeper training; and even micro-organism recognition training in medical schools (12).

Operative effects of tachistoscopic training.--The prime objective of tachistoscopic training is to enlarge the individual's field of perception at a greater speed. This goal is analogous to the objective of Gestaltian psychology--looking at the whole and not at its parts. Tachistoscopic training develops the ability to see the whole form as a unit rather than to synthetically integrate the form's details. Essentially, the normal eye lens is trained to become a wide-angle lens with a greater speed of recognition by forcing concentration. The short duration of the flashed tachistoscopic image accomplishes this because the eye does not have enough time to make more than one fixation to see the whole picture, and, hence, the eyes must learn to broaden their perceptual scope to perception of the whole form. The duration of the flashed picture also requires speeded concentration of vision for the fraction of a second exposure or no picture will be seen. One individual, after training, had his perceptual scope area expanded three hundred per cent.

Grasping the whole of the subject under view as a unit is of primary importance in this training. Children have this condition as a normal state, but schooling causes the adult from his first days of learning to read individual letters. He sees disjunctively and minutely. It is the original ability that tachistoscopic training tries to regain. Some tests in experimental psychology have shown that this ability of grasping the whole is natural in children. A four year old daughter of a digit-reading champion exceeded his ability in perceptual speed of recognizing pictures (13).

Renshaw has experimented with exposure times of several millionths of a second with controlled illumination of the viewing field. However, a psychology report on aviation evaluated on a limited test basis the results to be obtained from reducing the exposure time. This test concluded that no differences in recognition proficiency were realized from groups trained separately at one second, one-tenth of a second, and one-fiftieth of a second exposure times (14).

Renshaw reported the findings of a laboratory controlled and tested group in which the subjects reading scientific text material increased from 468 words per minute to 775 words per minute on new scientific text material. He also gives evidence that 0.0005 second for seven digits is the minimum exposure time for immediate and perfect oral reproduction.

Concerning the role of digit training, this paper states:

> . . . it will be shown that once skill is developed in the formal process great improvements may be seen in other functions of different content. After even relatively limited digit skill is attained, for example, the indices of comprehension and speed in silent reading will show marked gains. And we will see that from digit training alone, given on the horizontal retinal meridians, the visual form fields of the eyes are significantly expanded in both the horizontal and vertical axes (15).

General tachistoscopic training procedure recommendations.--Since the tachistoscope training aids the person in re-educating himself in the art of seeing, little difficulty, if any, arises in transferring the training to everyday circumstances.

The length of the training periods varies for children and adults. Renshaw utilized a thirty-six hour week for four weeks in the specialized program of aircraft recognition training (16). In only thirty three-quarter hour evening sessions, the Battelle Institute program was completed. Each session comprised about twenty-five exposures. However, Renshaw felt that double this time would have developed more satisfactory results (17). He further recommended reviewing completed steps of training, and he emphasized digit training as an integral stage of development (18). Barnette recommended no less than thirty sessions, with fifty to sixty as more desirable for retention. The sessions should be of approximately sixty minutes each with three to five sessions held each week (19).

For tachistoscopic training of high school and adult levels, Barnette proposed these training stages (20):

1. Line and form drawings: learning to see.
2. Digits and spaced digits: widening of span and accuracy gain.
3. Words: word recognition.
4. Phrases: unitary perception of thought units.
5. Phrased sentences: rhythmic and left-to-right fixationing.
6. Sentences in one line: sentence seeing.
7. Paragraphs: developing phrase reading.

The initial targets in each stage should be portrayed at speeds as slow as one-tenth of a second, and progress in steps of one twenty-fifth, one-fiftieth to one one-hundredth of a second exposure time. A presentation sequence for the instructor to follow is to (21):

1. Have the trainees observe the target area to place their attention at the fixation point of the target to be presented.
2. Alert the trainees for target presentation.
3. Notify the trainees of the type of target, such as a word or a group of digits.
4. Flash the target picture to be observed.
5. Have the trainees pause, still looking at the target area for afterimage effects.

6. Have the trainees respond by oral or written answers.

Active response and participation are desirable for any stage of training. Passive observation has had poorer results than when each trainee has had to record his observations and compare them to the correct answers. Barnette recommended that the pre-exposure, exposure, and post-exposure illuminated fields be substantially equal in intensity in order that no persistent afterimages will exist. This condition is most easily met when the contrast between environment and target fields is negligible. The physiological purpose is to avoid cases of retinal shock (22). Further, it seems that normal conditions surrounding training would have a better opportunity to be usefully transferred to the individual's normal environment following training.

Existing practices in time study training.--The great majority of academic or industrial time study training methods are essentially "learn by doing." Yet one finds examples such as that of the time study man with a number of years' experience whose untrained reaction was so slow that he could not record elements less than four-hundredths of a minute (23). A comparison can be made here between this reaction time and the fraction of this time required by a tachistoscopically trained person. The current practice is simply to tell the trainee how to read the stopwatch scale and how to place the observed values on an observation sheet. Application practice is staged by having the first timing jobs with fairly long elements. Progression is then gradually made to shorter element times, approaching four-hundredths of a minute or less for some of the elements. Some texts do discuss the advantages of having trainees simultaneously time the same job, and then compare and analyze their readings. However, examination of this method shows that there is no plan or principles of instruction other than that of "sink or swim". Other than giving them more practice, little assistance is given to those observers having difficulty; further, the trainee has learned no thought pattern for retention.

The results of such training are that a poorly skilled observer spends too much time timing the job and not enough time observing the job conditions, which is his real task. Even the qualified time study observer may be badly proportioning his time study work. In this case, training by practice offers little to the industrial engineer doing only sporadic timing work.

Some investigation and development of training methods have been conducted at New York University. The device used there consists of an endless tape driven by a fixed drive; white, numbered spots on the tape at measured intervals pass a fixed pointer. The trainee records the time of spot and pointer intersection, which is later checked against the time scale. Another training method which has been developed is the flash test; it also compares the trainees' observations with known times. In this method an instructor follows a pre-arranged observation sheet with a stopwatch, and presses a neon glow lamp switch when the endpoint time occurs (24).

However, it is evident that neither of these two methods develops the span of perception gained by use of a tachistoscope. On the contrary, both methods tend to create an artificial atmosphere for the trainee and cause him to focus his vision extremely narrowly. The majority of other texts discuss only the mechanical factors of scale reading and observation sheet recording.

Summary.--General tachistoscopic training is broadly applicable to all types of eye use. However, it has not been applied to training persons who are concerned with reading a time study stopwatch. Winger summarizes the general advantages of a full program of tachistoscopic training by stating that this training will:

1. Develop unitary seeing through practice in perceiving an object as a whole without reference to its parts.
2. Develop increased power of peripheral interpretation and result in an increased visual span or increased span of recognition.
3. Develop a particular skill in the formal processes which will provide an improvement in functions of different content.
4. Develop the ability of the trained perceiver to see more accurately in shorter exposures than in longer ones.

5. Develop increased speed of reading and increased comprehension.
6. Develop increased form fields, both vertical and horizontal.
7. Develop one's visual acuity to such an extent that myopia will be reduced as far-point training progresses.
8. Develop the ability to reduce the prevalence of letter reversal habits in reading and reproducing what is read.
9. Develop increased ability to concentrate through the necessity to look actively in order to see what is exposed.
10. Develop increased interest on the part of the observer in whatever task is at hand and allow for personal expression of certain talents.
11. Develop increased grouping skill and promote greater coherence and unity in the visual perception of forms.
12. Develop the ability to convert visual reactions into kinesthetic reactions.
13. Develop relaxed motor responses through elimination of the unnecessary attention to techniques.
14. Develop a better organized and more flexible type of thinking (25).

The evaluation and review of existing training procedures show that very little effort has been made in the methods of training in reading a time study stopwatch. Yet the problem as described in the Introduction is far from insignificant. The attempt of this experiment is to utilize tachistoscopic training advantages such as described to give solution to these problems.

CHAPTER III

EXPERIMENTAL DESIGN

Assumptions and parameters.--The survey of tachistoscopic training literature indicated that it would be of practical value for time study training. When using the continuous method, the major difficulty occurring in stopwatch reading results from the continuously moving dial hand. It was considered that the speed of recognition to be obtained from tachistoscopic training would resolve this problem. The other benefits of this type of training also would be advantageous.

The determination of the length of the training program was an important decision in this experiment. External considerations determined this length. Regardless of the merit of the full program, an application of tachistoscopic training would have to be made within the customarily available course and laboratory time for practical usage. General instructional conditions allow three to six hours of laboratory utilization for stopwatch instruction and practice. Usually the first three hours have no other function, while the second three-hour laboratory period may be used to gather data for initial analysis work by the individual students. It was also desirable to consider the possibilities of reducing the present time necessary for such training.

Based on these opinions of the time parameters involved, the total length of training time chosen was the equivalent of a single three-hour laboratory period. The experiment is limited by this assumption. Since the initial topics of training in an organized tachistoscopic program include digit training, it was assumed that the desired results could at least be partially achieved in the limited time program of three hours. Realization that the stopwatch scale requires only the perception of one number plus a ten part scale estimation, or the equivalence of two numbers, aided in the determination of this assumption. Detailed estimation of the instructional facts necessary for initial use of the stopwatch and observation sheet was made.

The outline of this proposed training period consisted of three stages: (1) technical instruction, (2) training, and (3) the experiment data-taking session of actual practice. Coordinated available time, expense, and the difficulties ensuing from the use of groups of subjects are the causes that limited the number of training procedures to be tested. Two groups finally were established. They were the tachistoscopically trained and classically trained groups. The classical group was trained by current training practices and performed the function of a control group.

However, a pertinent requirement of the subjects to be trained is a lack of any prior experience: this experiment is concerned with the training methods for initial indoctrination of stopwatch time study. Hence, training by either of the above methods invalidates that subject from further training or testing. This was simply resolved by keeping separate the respective training method groups.

The training device was assumed to be of the same training value and principle as a tachistoscope. The device used was an improved operation design similar to the original one. This design was chosen in preference to films or some other means, such as specially prepared slides to be used in an actual tachistoscope, because it is simple and easy to construct. The face behind the two shutters is a model of a stopwatch face; this design was considered logical for training for this special purpose. There was no timing exposure control; the operator opened the shutters which were closed by springs.

The continuous method of time study observation was chosen as representing the better industrial practice. The experiment design made no attempt to measure differences between the snapback and continuous methods of recording. All values recorded were raw or observed times; there was no rating.

Detailed establishment of the various instructional facts necessary were outlined. The instructional problem was the choice of the lecture material concerning the manual usage of the stopwatch. It was decided to emphasize heavily such instruction for all trainees regardless of the training method used. This decision was made on the assumption that the training device alone would be evaluated and not coupled with guidance on how to read the stopwatch. This lecture was given simultaneously to both method groups. This was a major factor in the experimental procedure, as training plans are often qualified by the statement, "with proper guidance, the device will work."

Finally, following standard psychological testing procedures, the two groups were originally balanced in as nearly equal populations as possible (26). For the third stage, which had to be spread over a number of days, the subjects were evenly chosen at random from both training groups to eliminate any effects attributable to the assembly worker's variations in job performance.

Based on these assumptions, the parameters, stages, and practices chosen were expected to reflect a realistic evaluation of normal instructional environment for application.

Procedure design.--The first stage of the proposed training period required one hour for instruction in the techniques necessary for taking time studies. All subjects received this training at the same time, regardless of the method they were to be trained in during the second stage. No subjects were told the type of training they were to receive until the end of the first stage. No titles were given to the types of training; subjects were given their assignments as "A" or "B".

The second stage consisted of the training stage for the separately grouped subjects. All subjects were requested not to discuss the training they received until after the whole experiment was completed, and then they were told the reason for this request. As far as is known, full cooperation was received in this factor. At separate times the training was given for each of the two groups. The subjects received either tachistoscopic or classical training. One hour was devoted to this stage.

The third stage lasted for several days with the subjects randomly and evenly chosen from both training groups. It was at this stage that the experimental data were taken. The mixed group took time studies of a previously unused part assembly of a more difficult nature than had been used for stage two. Coupled with their timing of the assembly job, micromotion pictures were taken to act as a measurement base or datum plane. The micromotion time data were used as the base to measure the bias of the individual subject within a training group. The measurement base was operative during all assembling of parts by the operator; however, a foreign element was required for the film-changeover period. Not quite one hour was needed for this stage.

Subjects.--In the late spring of 1957, a letter was circulated requesting volunteer subjects for this experiment (see Appendix One). The eligible population of industrial engineering undergraduates was small, so that any background was acceptable. One evening before the first stage, a meeting to fill out personal data sheets was held (see Appendix One). The only information offered by way of explanation was a verbal repetition of the letter of request. Emphasis was placed on volunteer service since three hours of participation were required; the work also was somewhat tedious in nature from the subject's viewpoint. Moreover, the seriousness of purpose would have to be reasonably equal to that of a course student (at his first laboratory period).

Provisions were made to handle thirty-six subjects. Personal data sheets were received from forty-two volunteers. At random thirty-six volunteers were chosen from the engineering student volunteers. Ultimately, because of drop-outs and missed attendance, twenty-six subjects completed all of the three one-hour training stages. Some of the responsibility for the loss can be attributed to the unfamiliarity of the experimenter in what could be expected from a large group of volunteers; part of the loss was attributable to the responsibility level of freshmen. Subjects with any prior experience, of course, were ineligible, which caused the reservoir of volunteers to be composed largely of lower classmen.

The majority of volunteers were industrial engineering students. No affecting handicapped volunteers were used.

On the basis of the personal data sheet information, the subjects were categorized on the bases of age, academic average, sports participation, and degree background (see Appendix One). The sub-categories were:

1. Age: twenty-one years old, over twenty-one.
2. Academic average: less than 2.0 (2.0 equals "C" grade), 2.0 to less than 2.4, and 2.4 and up.
3. Sports participation: active, moderate, occasional, or random. Subject determined his category on the basis of the definition given.
4. Degree background: industrial engineering, other engineering.

On the basis of this information, equality was made between the two groups to receive training. To eliminate bias, random assignment of the subjects to a training group was made. The procedure used was to break each category into its sub-category and randomly assign a personal data sheet to a pile of one of the two training groups. This was accomplished by sorting each category in the above order in turn.

Equipment.--The prime piece of equipment was the device to be evaluated--a modified mock-up of a stopwatch (see Figures 1 to 3). This device is a reproduction of a stopwatch face with a turnable but non-moving dial hand. The stopwatch face is covered by two horizontally opening doors or shutters. The shutters are manually opened against spring opposition; one control handle operates both shutters. When the control handle is released, the shutters snap shut. Sponge rubber padding virtually eliminates any noise factor. Its basic materials are wood, bristol board, light ropes, pulleys, and a spring. The mock-up face is proportionately in scale at fourteen feet to the approximate location of a time study board when held in its recommended position. The device was used solely for the tachistoscopic group training during the second stage.

Standard decimal-minute stopwatches and time study boards were used; left hand boards were available. Printed observation sheets were furnished to the subjects. The micromotion equipment consisted of a microchronometer, sixteen millimeter camera, projector, floodlights, exposure meter, and camera tripod. The time studies were made at a workplace layout with fixed plywood work bins (see Appendix Three).

The last two stages were conducted in an enclosed laboratory, moderately ventilated, with adequate lighting by overhead fluorescent lights.

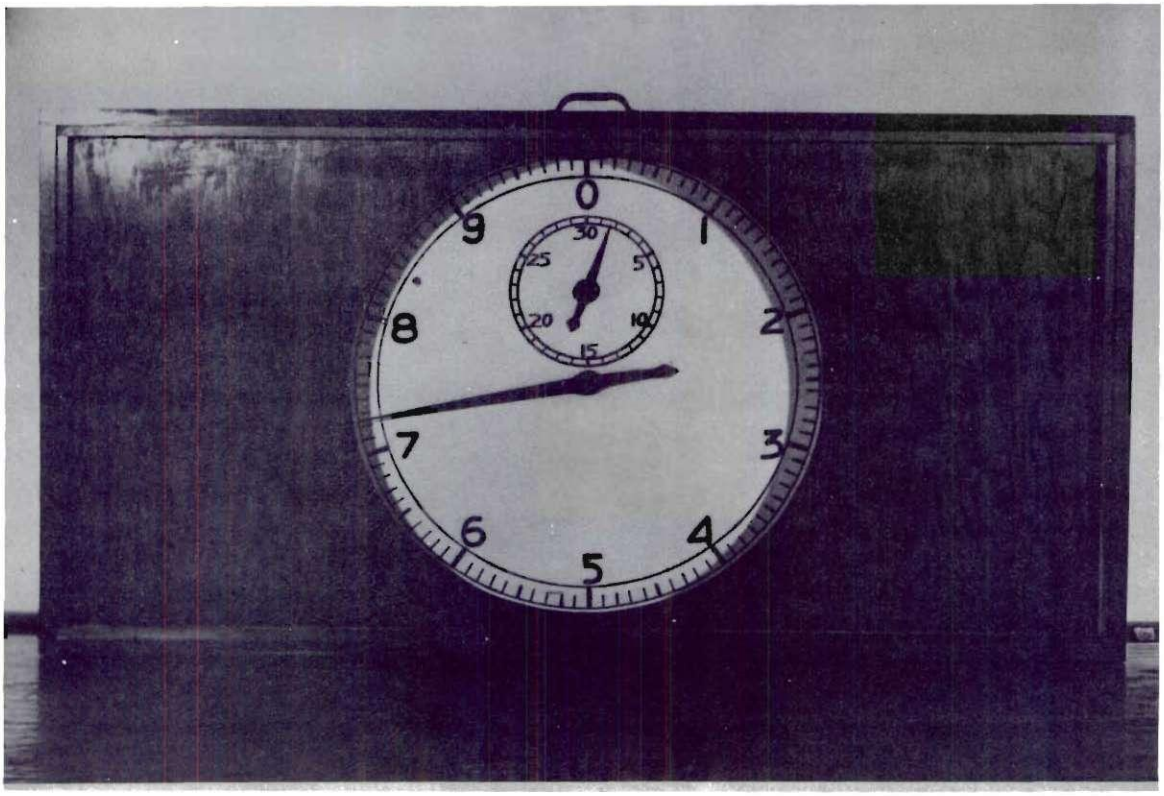

Figure 1. Front View of Tachistoscopic Training Device with Shutters Open for Viewing.

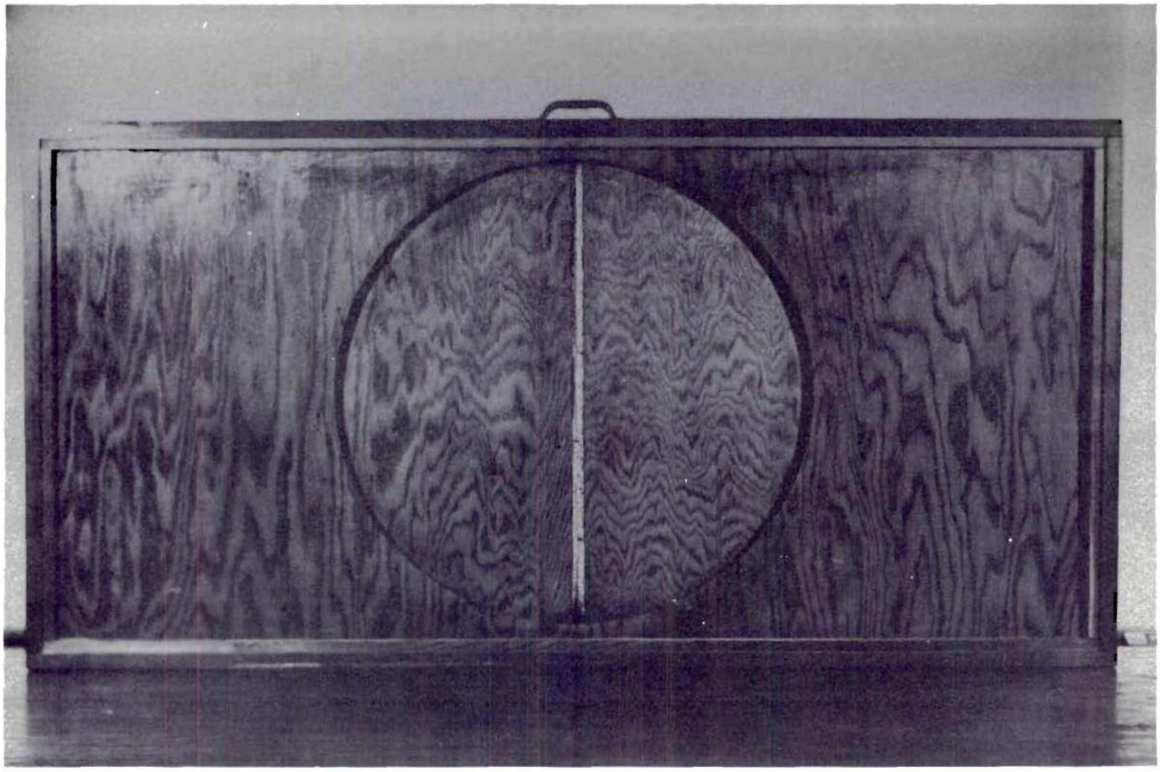

Figure 2. Front View of Tachistoscopic Training Device with Shutters Closed.

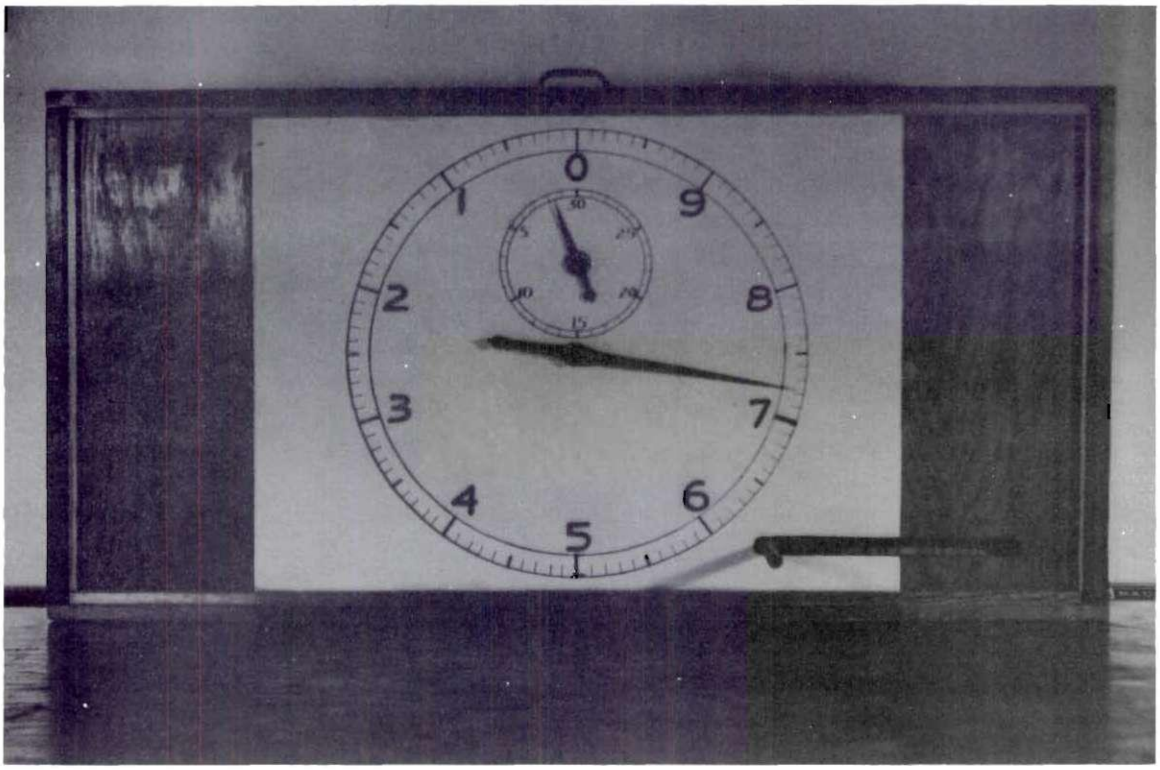

Figure 3. Rear View of Tachistoscopic Training Device Showing Shutter Operating Handle at Lower Right in Closed Shutter Position.

Schedule.--Following the first mass meeting with both training groups, the subjects were told that the experiment would comprise three one-hour meetings. At this meeting the personal data sheets were filled out, and the subjects were requested to come the next evening if they were willing to volunteer. Following the first stage of the experiment, individual assignments were made for the remaining two stages. Availability of equipment and scheduling convenient to the group necessitated more than one day per stage. Generally, all meetings were held in the early evening. The resultant schedule is as follows:

Monday: Completion of personal data sheets and request for volunteers.

Tuesday: Stage one mass lecture for both training groups.

Wednesday: Stage two for classical training group.

Thursday: a. Stage two for tachistoscopic training group (during the day).

b. Stage two for classical training group (during day).

c. Stage two for tachistoscopic training group.

Friday, Saturday, and Sunday: No meetings held

Monday: Stage three for both training groups. Subjects were evenly divided from both training groups.

Tuesday: Stage three similar to Monday.

Wednesday: Stage three similar to Monday.

Stage one details.--It was decided that it was necessary to receive the serious cooperation of the subjects, if normal conditions of classroom-atmosphere data were to be received. A lack of interest would result in ridiculous time study data. For this reason, an attempt was made to motivate the subjects to gain their full participation, which is recommended psychological testing practice (27). Besides receiving the necessary technical information, the subjects needed to grasp the relative perspective of their task, as their attitude would affect to a significant extent their performance. To meet this problem, heavy emphasis was placed on indoctrination in the role that time study plays in the industrial engineering perspective. This was also felt desirable on its own merits.

The lecture nature of stage one requires an instructor. Because an instructor effect can cause considerable bias of results, stage one was presented to all subjects of both training methods at the same time. Therefore, all subjects received training under the same specific conditions; any human bias in emphasis would be equally distributed in both training groups. The subjects were told that the objective of this program was the evaluation of some training procedures.

Lecture notes were prepared for stage one training. Several stopwatches on time study boards were circulated among the subjects during the lecture. The first part of stage one was concerned with developing subjects' motivation and their perspective in the use of the stopwatch. The outline of this information is given in Appendix Two.

At the beginning of the period, the subjects were requested to pretend that stage one was a lecture. They were requested to take notes (or pretend to) and act as if this lecture was given in a course for which they were receiving credit. Excellent cooperation was received; the subjects' attitude was as satisfactory as that of a regular class session. The remainder of stage one was concerned with the technical information necessary for the experiment to be conducted. This also included, as planned, stopwatch operative suggestions and hints. The topics covered appear in Appendix Two.

The subjects proved cooperative and seemed to show good reception of the material presented.

<u>Stage two, classical training</u>.--Each subject obtained a time study board with stopwatch attached and observation sheets. A brief summary of the use of the observation sheet and of the recording of endpoints, as well as more explanation on how to record foreign elements, was given.

The remainder of the period was spent in actual time study. The elemental descriptions with underlined endpoints were presented on a blackboard and copied by the subjects on their own observation sheets. Practice was obtained from timing three operations; the operations were progressively more difficult. The operations timed were:

1. West Virginia University beats Pitt. This was written repetitively for approximately twenty times and included timing of simple foreign elements. Endpoints were initially overexaggerated. The elemental times ranged from 0.30 to 0.40 minute.

2. a. Grasp paper, fold across width, move to stapler, hit stapler.

   b. Take stapled paper and walk to packing box, place in box, walk back to workplace, sit, start to grasp next sheet.

   Again endpoints were initially exaggerated. The operation was performed at a worktable with a fixed workbin layout. Approximately twenty cycles were timed. The "a" elemental time averaged 0.09 minute; "b" element averaged 0.18 minute. A foreign element was included.

3. a. Pick up u-bolt and clamp, move together and assemble, get first nut, screw on nut, release nut.

   b. Get second nut, screw on nut, move assembly to disposal box, drop release.

> The operation was performed at the same workplace layout; element endpoints were initially exaggerated. Approximately fifteen cycles were recorded. This job was more difficult, with the "a" element time averaging 0.10 minute and the "b" element time averaging 0.07 minute.

This was the end of the training stage for the classical group. Fair results and good cooperation were gained. The subjects identified their observation sheets only by name. During the whole period the subjects were reminded to relax and get the job rhythm, to keep the watch and work in a straight line, and to "grab" or "snap" the endpoint reading.

Stage two, tachistoscopic training.--Each subject obtained a time study board with stopwatch attached and observation sheets. A brief summary of the use of the observation sheet and of the recording of endpoints, as well as more explanation on how to record foreign elements, was given. During the whole period, regardless of whether they were observing the device or an actual job, the subjects were reminded to relax and get the job rhythm, to keep the watch and work in a straight line, and to grab or snap the endpoint time. The basic procedure recommended by Barnette was used to take the tachistoscopic readings. The subjects were instructed by these words: (1) ready, (2) now (reading was then flashed), (3) pause and keep looking at the device,

(4) now record your reading. Normal room lighting was maintained during this period. The device was placed just above head height under a fluorescent room light. Illumination was aided by one distant floodlight. The subjects recorded four elements of a mythical job on their observation sheets; foreign elements were included. The endpoint times were taken from a pre-arranged observation sheet.

The first exposure times were long to enable the students to become familiar with recording the values. The exposure time was then decreased to as fast as the device could be operated. After each one or two observations, the actual readings were read to the subjects. Approximately thirty-five cycles of four elements were observed. After the initial exposures, the exposure time averaged nineteen winks (wink equals 0.0005 minute) or 0.57 second--approximately six-tenths of a second. The peak exposure time was thirteen winks or 0.39 second.

The psychological principle of transfer was incorporated in the outline of stage two tachistoscopic training.

> Transfer occurs when training in one task affects performance in another. In the development of complex skills, it is very important that the training be so arranged and taught that the acquisition of one skill does not detract from the acquisition of another, but rather that it facilitates the learning process as a whole (28).

Further, there was a several day schedule delay before application of training to the task for which it was given.

For these reasons the principle of transfer was adopted by devoting the remainder of stage two tachistoscopic training to actual time study.

The operation studied was identical to number three operation as described in "Stage Two, Classical Training." Approximately sixteen cycles were recorded. Foreign elements were included.

The subjects gave good cooperation and showed good humor when observing the training device times. The subjects identified their observation sheets only by name.

Stage three.--This was the ultimate stage where the data for experimental analysis were gathered. The results of the respective training methods were measured in this stage. This stage required no instruction; the subjects were requested to recall the methods of recording endpoint times and foreign elements.

After obtaining their equipment, the subjects copied the elemental descriptions to be used from the board. The operation to be timed was more difficult than they had previously been accustomed to by the training given. The operation was the assembly of a three-quarter inch globe valve (see Figure 9). It consisted of five elements with average elemental times ranging from approximately 0.03 to 0.16 minute.

The assembly of the job took place at the workplace layout previously described (see Appendix Three). Several practice trials were held to acquaint the subjects with the endpoints and sequence of assembly; clear understanding by the whole group of the endpoints was emphasized, since the analysis would measure the subject's bias based on the defined endpoints. It was explained that the necessity of film-changeovers would cause foreign elements, and that ample warning would be given.

The micromotion studies were taken at the standard speed of sixteen frames per second (see Appendix Three). Any greater speed would cause too wide an interpolation gap between microchronometer wink readings. With a one hundred feet film capacity, a slower speed would interrupt the operation too frequently for changeovers of the film cartridge. Measurement of the camera speed was not an important factor since a microchronometer was located at the workplace layout.

The operator of the camera acted as the scheduler. The camera was started before the start of the operation, and then a signal was given to start assembling. When the camera gauge approached ninety feet, another signal was given. Upon this signal the assembly operator completed the current assembly and stopped the operation, after warning the subjects. The subjects would then record the time as a mythical foreign element such as "talk to foreman." During this time the parts were disassembled, and another film cartridge of one hundred feet was inserted.

This same procedure was followed until three hundred feet of film had been taken. Each one hundred feet of film allowed enough time to complete twelve to fourteen assembly cycles. This same method was followed for all three days scheduled for stage three. The subjects were occasionally reminded to relax, get the rhythm, keep board and job in a straight line, and grab or snap the reading.

The first six to eight cycles observed by the subjects were assembled with exaggerated endpoints. This same exaggeration was made for the first cycle after each foreign element. All observation sheets were identified only by name and date; the students did not post their readings. Good cooperation was received. This stage was completed at the end of the third film cartridge.

Procedure summary.--It was considered feasible that a limited tachistoscopic training was practicable, since the training was for a simple special purpose, and that the purpose was an initial stage of generalized tachistoscopic training. This consideration was determined by the limited time available for time study training in normal course outlines. The total training time allotted was three hours; the last hour was used to evaluate the results of classical versus the modified tachistoscopic training.

The device designed was assumed to have the same operational principles as a commercially available tachistoscope. Recommended sequence steps of operation for general usage were followed in the operation of the proposed device used for special purpose training. The device is a mock-up of a standard decimal-minute stopwatch.

All eligible subjects had no prior time study or related experience. Throughout the experiment, all choices or decisions concerning the arrangements of subjects were made at random. The subjects were volunteer engineering students.

Information on how to read the stopwatch in a practical manner was presented solely for the purpose of evaluating the capabilities of the training device. The experiment measurement control used was micromotion filming of the same operation being timed by the subjects. All values recorded were observed or raw times.

CHAPTER IV

ANALYSIS OF EXPERIMENT

Introduction.--A factorial design of a mixed model nature with one classification nested was used in this experimental investigation. Nesting was required since the subjects were not eligible for training in both methods; the subjects had to be initially inexperienced. The main effects considered in this study were subjects (nested in methods), training methods, and the time study elements.

Classification of these variable as fixed or random effects had to be determined. Fixed variables,called Model I variables, are those "whose parameters involved are means and the issues of interest are concerned . . . with the differences between pairs of them" (29). Random variables, called Model II variables, are those "whose parameters involved are variances and their absolute and relative magnitudes are of primary importance" (29). Therefore, it was determined that, since subjects were chosen at random from their population, subjects were a random effect. Methods and elements are appropriately treated as fixed variables, and, hence, are each fixed effects. The classification of the variables (see Table 1) permitted inferences about the whole population of subjects, but only the differences between

Table 1. Classification of Variables

Source of Variance	Abbre- viation	Sub- script	Symbol	Number of Levels	Model
Methods	M	j	M_j	2	I
Elements	E	k	E_k	5	I
Subjects	S	i	$S_{i(j)}$	13	II

the methods and between the elements studied. A first order interaction was interpreted as:

> The interactions . . . represent differential effects of one of the factors caused by different levels of the other (or others). In deciding about the interactions among a given set of factors, the interaction is treated as Model I if all the factors involved in the interaction are Model I; otherwise, it is treated as Model II (30).

The mathematical model to describe this experiment is:

$$x_{ijk} = \mu + S_{i(j)} + M_j + E_k + ME_{jk} + \epsilon_{ijk}$$

The analysis of variance mean squares and the values of the expected mean squares are outlined in Appendix Four.

<u>Measures of objectives</u>.--The prime objective of this experiment was the determination of the relative values of the tachistoscopic and classical training methods. It became necessary to determine the measures to evaluate the two methods. Time study practice has two conditions which are prerequisites of good results. It is desirable that the observer has good accuracy. It also is desirable that the standard deviation, or precision, of his readings be small. This second condition is of considerable importance because a relatively small sample of times is taken to estimate the time required for an element of an operation. Hence, an observer may get accurate results on a long run average, but with a small sample his mean value may be

distorted by readings with a preponderance of deviations in one direction. The observer lacks consistency of results when his standard deviation is great.

The solution to this problem was resolved by establishing that both the accuracy, measured by the arithmetic mean, and the precision, measured by the standard deviation, would be separately investigated. Micromotion techniques permitted precise measurement of the elemental times within one two-thousandth of a minute.

From the micromotion measurement the difference of subject values from the true values could be readily determined. This results from the fact that the value recorded by the subject is composed of subject bias plus actual elemental time. The bias, or difference, of the observed time and the true value can be expressed:

$$\text{Bias}_{\text{subject}} = \overline{X}\ \text{recorded}_{\text{total}} - \overline{X}\ \text{micromotion}_{\text{control}}$$

The measure of precision chosen was the variance (variance equals standard deviation squared). The evaluation of the training methods requires that only the subject precision be evaluated. Reference to a common fundamental of statistics will permit this calculation. The sum of the variances of the parts equals the variance of the total, provided that the parts are statistically independent. The total value recorded by the subject is composed of the subject's timing variation plus the timed variation inherent in the operation. The operation has its own deviations resulting from the operator and materials. The micromotion variance is composed only of the operation variance within its accuracy limits of measuring. The fundamental expression is (31):

$$\sigma^2_{total} = \sigma^2_{part_1} + \sigma^2_{part_2}$$

The recorded time study value by the subject is the total variation composed of timing and timed variations. The calculation is resolved by rearrangement of the above expression to:

$$\sigma^2_{subject} = \sigma^2_{total} - \sigma^2_{operation}$$

The variances attributable to the total and to the operation can be found from the existing experimental data by reference to the calculation expression of (32):

$$Var_{sample} = \frac{1}{n - 1}\left[\sum_{i=1}^{n} x_i^2 - \frac{\left(\sum_{i=1}^{n} x_i\right)^2}{n}\right]$$

where: n = number of readings

x_i = value of individual reading

Precision attributable to the subject is easily found by subtracting the micromotion variance of the sample from the sample variance of the times recorded by the subject in stage three operation.

The preceding procedures for finding accuracy and precision measures are applicable only if the subject missed no time study readings. Otherwise, the measures do not reflect the same populations. Another objective is to consider the percentage of misses occurring in each method of training. To measure the same populations, it is necessary that the micromotion calculations be compiled from those element observations exactly coinciding with the subject observations. This requirement was accomplished by chronologically matching the individual subject's elemental time recordings with the parallel micromotion recordings and omitting those micromotion values without any corresponding subject value. This was done for each element of each subject.

Data reduction.--The original data tables for the analysis of variance were coded to ease the calculation burden based on the recommendations of Davies (33). Appendix Four contains the original data tables and conversion expressions.

One cell of precision data was noticed to be experimentally non-deducible; this cell was considered as a missing value. The procedure used was to complete the analysis of variance for the error sum of squares with the missing value as "x". Differentiation with respect to "x", set equal to zero, found the "x" value which would make the error sum of squares a minimum (34). This value was adopted, and the analysis of variance recalculated. The degrees of freedom for the total and residual are each reduced by one.

A basic assumption underlying the analysis of variance technique is that the experimental errors in the individual cell observations are normally distributed in order to make qualified use of the "F-distribution" (35, 36). If they are not so distributed, the use of a transformation of the original data is recommended that will develop this condition of normality. Bartlett recommends a logarithmic transformation for distribution of sample variances to improve normality (37). In this experiment the precision data was logarithmically transformed prior to analysis of variance calculations.

The systematic breakdown of all calculations to basic arithmetic steps was the manner used to collate and calculate the routine experimental data. This is clerically desirable for accuracy in handling large volumes of data, and permitting transfer of skill. The original time study observation sheets were posted while identified only by name and date; collation by the training method was done after the posting of elapsed times to reduce any possible bias.

Hypotheses.--As discussed, the objectives would be comparatively evaluated on the basis of the number of missed readings, accuracy, and precision between the two methods of training. If the proposed training method proves successful on the basis of these quantitative measures, the technique will be adopted; it also can be assumed that the goal of student's increased confidence in his ability will be realized.

To measure the accuracy and precision an analysis of variance statistical tool is employed with the following null hypothesis:

> The methods of training do not affect the accuracy (or precision), and that the values received are from the same populations.

Similarly, the null hypothesis for differences in the percentage of missed readings per training method follows:

> There is no association between the percentage of missed time study readings and the method of training.

A chi-square test of the total missed and observed readings per each method was used to test this hypothesis.

Rejection of any of these hypotheses would indicate a difference in methods for the particular evaluation. Examination of the original data would then indicate which method has better training capabilities. If a hypothesis is not rejected, it can be assumed that both methods are of the same population and their differences are only effects of random error.

<u>Results</u>.--This division is concerned with the quantitative and significance results of the analyses of variance and the chi-square test. Graphs of the methods times elements

interactions are included to aid interpretation. Magnitudes of the factors have been summarized by Method I, tachistoscopic training, and Method II, classical training. These summaries have Bias and Timing Variation columns. As previously explained, bias is the measure of subject accuracy; timing variation is the measure of subject precision.

The method's main effect is of most interest, since it measures a difference between training methods. Examination of Tables 2 and 3 shows non-significance between the methods of training. The null hypotheses of accuracy and precision were not rejected. Therefore, the training methods are statistically equivalent in their effect, even though the magnitudes indicate that the classical method is better from the following summary:

	Bias	Timing Variation
Method I	0.1647 min.	0.0544 min.
Method II	0.1565	0.0459
Difference	0.0082	0.0085

It should be expected that a non-significant main effect usually will not have its first order interactions significant. However, analysis of Figures 4 and 5 indicates that the non-rejection of the hypotheses may be caused by experimental conditions and not solely by the between-methods effects. The graphs indicate the possibility that non-significance is caused partially by the tendency of the

Table 2. Significance of Factors
Influencing Time Study Accuracy

Factor	Degrees of Freedom	F-test Comparison	F-test Ratio	Probability Level of Significance
Between Methods	1	Subjects	0.0097	Not significant
Between Elements	4	Residual	14.4871	0.0005
Between Subjects Within a Method	24	Residual	1.0422	Not significant
Method x Element Interaction	4	Residual	3.0984	0.025
Residual	96	--	--	--

Table 3. Significance of Factors
Influencing Time Study Precision

Factors	Degrees of Freedom	F-test Comparison	F-test Ratio	Probability Level of Significance
Between Methods	1	Subjects	0.8408	Not significant
Between Elements	4	Residual	5.3524	0.001
Between Subjects Within a Method	24	Residual	3.0720	0.0005
Method x Element Interaction	4	Residual	1.7878	0.25
Residual	95	--	--	--

negative and positive directions of biases or timing variations in a method to balance their effects. Further interpretation will depend on the results of the methods interactions.

The element's main effect is significant for both bias and timing variation. For accuracy, the null hypothesis has been rejected, and it can be assumed that the elemental biases are not from the same population. Similarly, it can be assumed that elemental timing variations are not from the same population. There was experimental consideration that this would result since the length of elemental time is a pertinent factor of timing with shorter elements being more difficult. Elements "A", "B", and "C" are "short" elements ranging from 0.03 to 0.06 minute. Elements "D" and "E" range from 0.09 to 0.16 minute; elements this size are expected to be relatively easy to time. Examination of Figures 4 and 5 parallel these expectations. Each element is composed of twenty-six subjects. The bias for long elements averages an understated 0.0474 minute. The bias for short elements averages an overstated 0.1387 minute. Without regard to direction the total average elemental bias is 0.1022 minute; no special significance should be placed on the direction of bias since the time study method used was the continuous observation method. The timing variation for short elements averages 0.0205 minute; long elements average 0.0190 minute. The total average timing variation is 0.0201

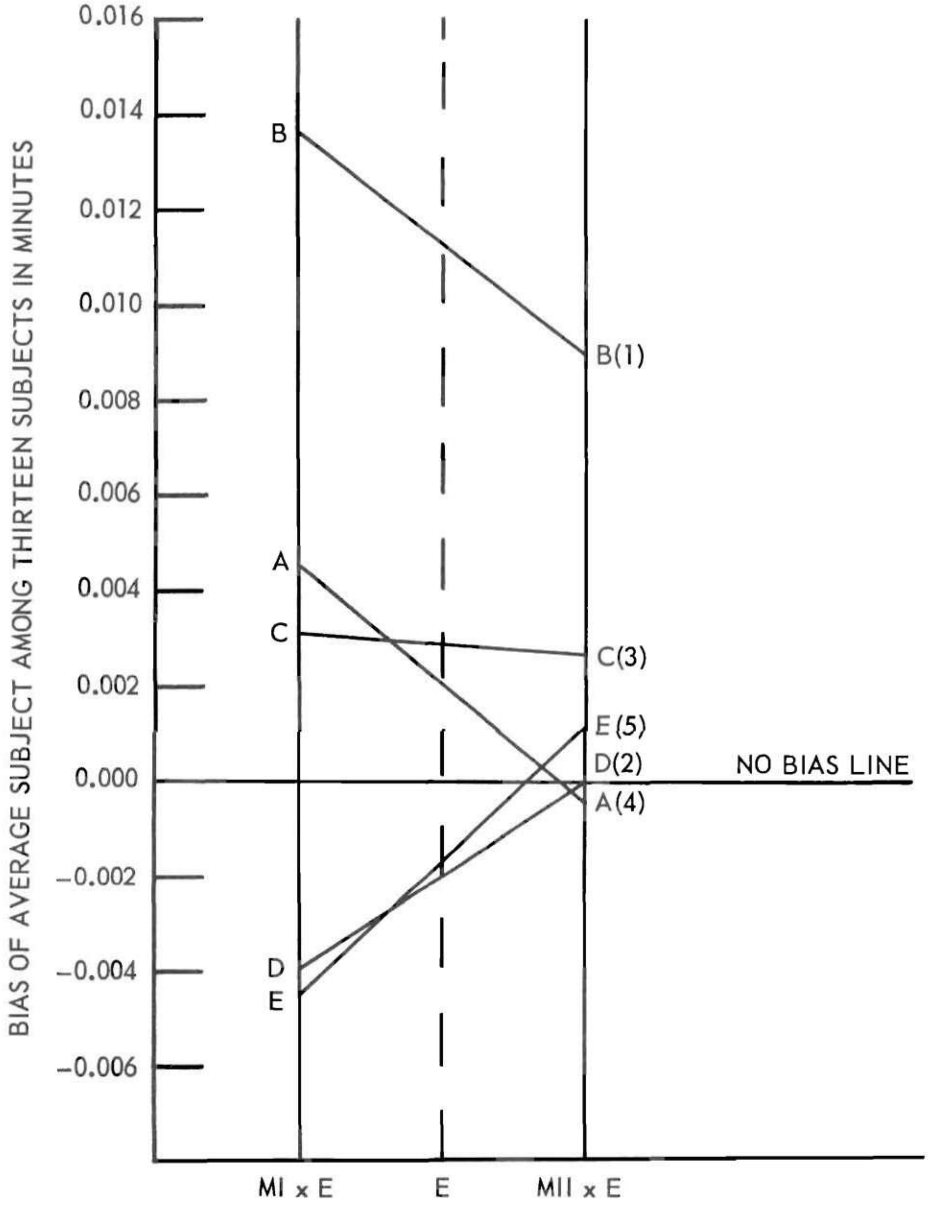

Figure 4. Graph of Methods Times Elements Interactions for Bias. Multiply "E" value by two to obtain bias between elements. Element letter symbols are lengths of elements in increasing order. Numbers in parentheses are the time study sequence.

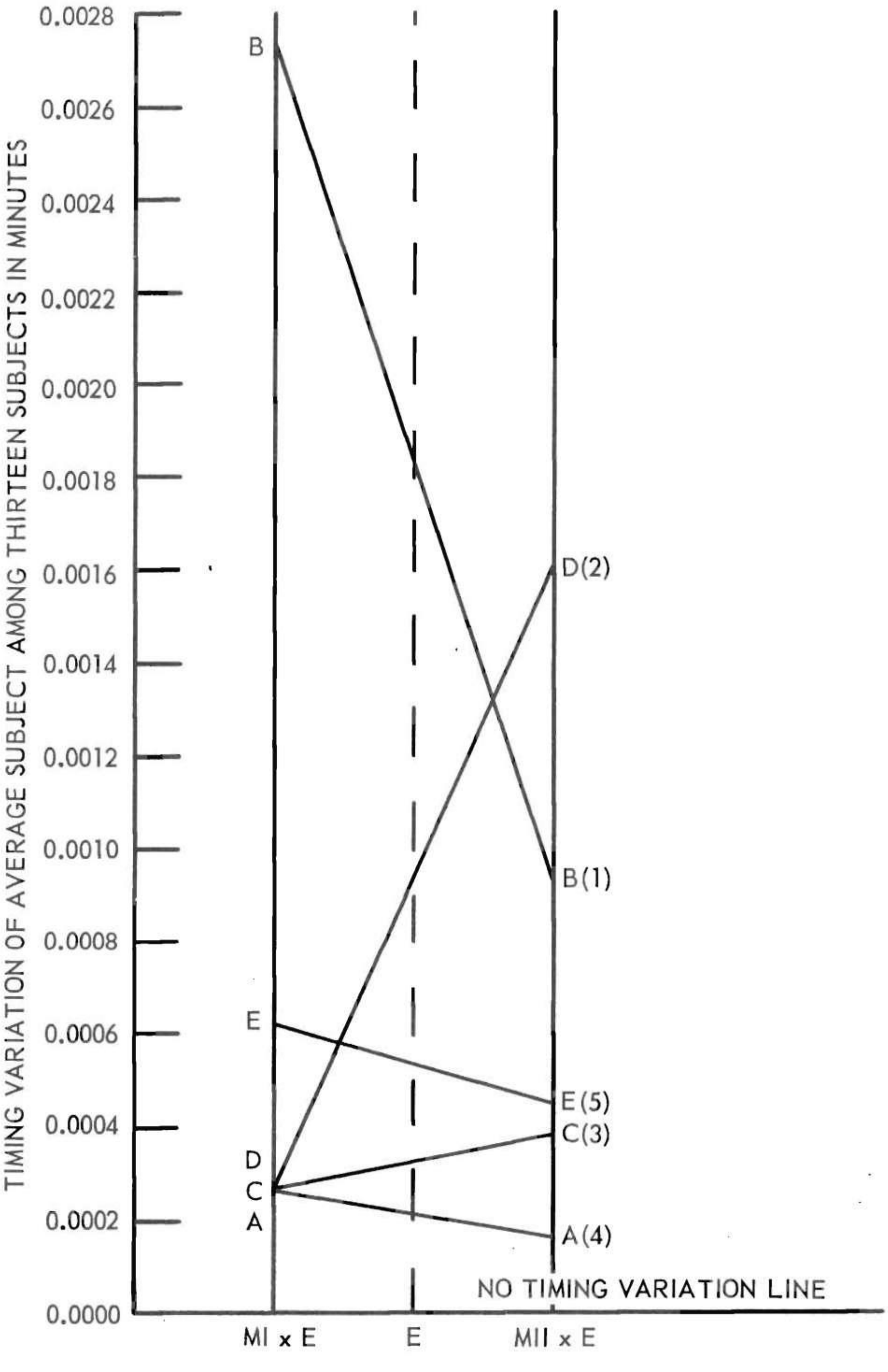

Figure 5. Graph of Methods Times Elements Interactions for Timing Variation. Multiply "E" value by two to obtain timing variation between elements. Element letter symbols are lengths of elements in increasing order. Numbers in parentheses are the time study sequence.

minute. The only experimental explanation for the extreme fluctuation of "B" element is that it was the initial element of each cycle; hence, it followed the foreign element. Its elemental parameters were not as precise as those of the other elements.

The subject's main effect which was nested within methods was found to be significant for timing variation between subjects. However, the bias null hypothesis was not rejected; it can be assumed that the subjects within a method are no different as concerns bias. The total average bias and timing variation, per subject is shown as follows:

	Bias	Timing Variation
Method I	0.0127 min.	0.0042 min.
Method II	0.0120	0.0035
Difference	0.0007	0.0007

The timing variation significance is reasonable since individuals are known to vary in their timing precision. The non-significance of bias is observed in common practice; observers tend to average the same mean time for a group of observations. The experimental condition of nesting allows observation of the differences between subjects within their respective methods.

The interactions of methods times elements prove most interesting in the evaluation of the differences between the two methods. The combined effects of methods and elements are questionably significant for timing variation; there is a small possibility that a particular method is of value in reducing timing variation. However, there is a significant effect resulting from the use of a particular method with an element to reduce bias. The average method times element interaction for bias and timing variation is shown as follows:

	Bias	Timing Variation
Method I	0.0329 min.	0.0109 min.
Method II	0.0313	0.0092
Difference	0.0016	0.0017

It is clearly evident from observation of Figures 4 and 5 which method favors bias and timing variation reduction. Examination of Figure 5 shows a moderate tendency for Method II to reduce timing variation, even though the tendency is non-consistent. Similar examination of Figure 6 shows a very strong tendency for Method II to reduce bias. Therefore, re-evaluation of the methods main effect should be made following the investigation of the methods times elements interactions. It then becomes evident that the classical method is definitely superior to the tachistoscopic method of training.

The chi-square test was used to investigate the difference between the two methods of the percentages of missed readings. The difference resulting from the two methods is highly significant; it exceeds the one per cent significance level (see Appendix Four). The classical method has only 13.9 per cent total misses; the tachistoscopic method has 17.5 per cent total misses.

CHAPTER V

CONCLUSIONS

Conclusions.--Investigation of the comparative differences of the measures of accuracy, precision, and percentage of missed readings between the two methods leads to the single conclusion in all cases that the proposed tachistoscopic training method does not offer the capabilities of the classical method. The present classical training procedure should be continued in use as the method of training in reading a time study stopwatch.

Limitations and analysis.--Analysis should be made of the possible contributing causes to these results. The experimental investigation operated under the following limitations:

1. Subjects were all non-remunerated volunteers who may not have had the same motivations that formal trainees would have.
2. Results are only a measure of engineering student abilities.
3. The two training method populations may not have been of equal ability.

4. The analysis is based on a small sample of subjects.
5. The operation used to measure the results of training was a manual assembly of a small part.
6. The experimenter was experienced in classical training; tachistoscopic training was a new effort.
7. Lack of experimenter's experience and recognition of psychological training problems involved in experimental use of humans.
8. The analysis attempted to evaluate solely the training device, which may not have been well designed.
9. Strict experiment time parameters were established as initial assumptions.

If the first seven limitations are ignored as nil effects, a qualitative interpretation can be made as to the possible major causes. Renshaw, in discussing the soundness of tachistoscopic training, states:

> In tachistoscopic training, the kind of result secured will depend, like the acquisition of any skill, on the proper use of the method, and on the realization that sufficient time and training must be given to extend skillful performance to or beyond that shoulder of the curve to improvement. When this is done, there is little or no forgetting (38).

It is suspected that the rigidity of the practical time available for training is a too limited parameter for learning curve considerations when using tachistoscopic training.

There is a definite question if the device, itself, is adequately designed to present the flashed readings. Exposure times were substantially larger than those recommended for general tachistoscopic training.

However, a more relatively realistic evaluation of the data might be considered. If relative significance is ignored, the absolute differences in trained ability can be considered. The experimental results as seen in Chapter IV when viewed absolutely show very small differences in bias and timing variation between the two methods. In this sense, the methods of training are reasonably close to equivalent in effect. Review of the experiment stages shows that this relative equality occurs with an almost two to one ratio of actual practice, since the third stage was used to obtain the data and should not be considered as preparatory training. Therefore, it is possible that further testing following slightly increased parameters would reverse the conclusions. Furthermore, it would seem that the qualitative objectives of gaining confidence and learning a principle of technique may not be directly proportional to the results of the quantitative measures in the long run. This long run consideration is only applicable, of course, to students who may be doing no time study for a considerable period; it would not be applicable to industrial technicians who immediately apply their training. The unresolved question then is which method offers better capability of retention in cases of sporadic practice of time study over the years.

Summary.--The present classical training procedure should be used for time study training. It offers greater absolute and relative accuracy and precision of time study readings. It is significantly better for maintaining a lower percentage of missed readings. Long run qualities of training are indeterminable from this experiment.

CHAPTER VI

RECOMMENDATIONS

Recommendations.--Time study training and also the general field of tachistoscopic training principles offer a considerable number of future areas of investigation beyond the scope of this experiment. Further investigations of the problems of this experiment seem warranted. A number of experimental problems and other areas are described in the list following:

1. An evaluation of refined time study tachistoscopic training should be done. The parameters would probably have to be similar, but the training equipment could be improved by resorting to such developments as motion picture films.
2. Coupled with number one is the evaluation of reduced exposure times. This is a pertinent effect of general tachistoscopic training.
3. An investigation could be made of the learning curve required for training qualified time study observers without training time parameter limitations.

4. Analysis of the relative retention capabilities of the two methods of training over periods of varying length would be desirable.
5. Upon development of a successful tachistoscopic time study training method, evaluation should be made of the relative proportions of tachistoscopic and classical training desirable.
6. Investigation of the personal characteristics of trainees necessary to become qualified time study observers for industrial positions of time study technicians is needed. It is desirable that this analysis include both the minimum and maximum levels of the general intelligence quotient reflecting job contentment.
7. Investigation of types of time study watch dials and color backgrounds should be made. Similar investigations of related problems have been reported by Plourd (39) and Chapanis (40). Related applications are becoming increasingly important in observations of multi-dial panels. This is a critical problem when a time element is introduced, as in observation of aircraft dials when flying.
8. Areas of investigation in the relations of

tachistoscopic principles and the information theory are suggested. The following layman's interpretation is of interest:

> An artist was doing a landscape from the window of a windmill and discovered that the visual memory of the scene was more vivid than when he had done other paintings. He finally concluded that the windmill blades, flashing across his line of vision and giving him a series of rapidly repeated images, were responsible for this phenomenon. The belief that he saw more in a flash is a principle of tachistoscopic training (41).

The question of analogy here is whether the "noise" of information transmission was reduced for better communication. Experiments could be conducted to validate the possibility of a relationship to the existing expressions of the information theory. Reading rate investigations of the information theory have been made by Pierce and Karlin (42). Other investigations have been reported by Quastler (43).

Summary.--It is recommended that further investigations of time study training procedures be made. Their subjective values to be derived are improved student confidence and better retention of training principles for use at any later period.

A fruitful field of investigation is the possibility of discovering a theoretical relationship between tachistoscopic theory and the information theory. Establishment of such a theory and a mathematical quantification would open new approaches to the arts of communicating information.

APPENDIX ONE

SUBJECT INFORMATION

Table 4. Summary of Personal Data of Subject Categories. Number of Subjects Per Category Are Shown

Category/ Sub-category	Method I (Tachistoscopic)	Method II (Classical)
Age: > 21	6	6
≤ 21	7	7
total	13	13
Academic Average:		
≥ 2.4	6	7
= 2.0 to < 2.4	7	5
< 2.0	0	1
total	13	13
Sports Participation:		
active	2	1
moderate	3	5
occasional	6	6
random	2	1
total	13	13
Degree Background:		
industrial engineering	8	8
other engineering	5	5
total	13	13

PERSONAL DATA SHEET OF THESIS PARTICIPATING SUBJECTS

Full name:____

Age:______________Weight:_____________Height:__________

Sex:______________Race:_____________Marital Status:_______

Town & State of High School:______________________________

No. semesters in college (incl. present):__________________

Degree working for:_____________________________________

Overall average as of last semester:________________________

Overall High School grade to nearest +/- letter:______________

*Veteran:*______________*L. H. or R. Handed:*________________

Circle most applicable (last two year period) sports participation category:

Random; now & then, mostly self-sports	Occasional; any time of year, with a bunch of fellows	Moderate; during parts of year, clubs, groups	Active; year round, athletic teams

What kind of sports:_____________________________________

List any physical handicaps:______________________________

List visual problems (wear glasses?):_______________________

____

Have you ever had any training, practice, use with a moving stop-watch that would disqualify you as a non-skilled timing observer? If you have eligibility questions describe your familiarity:________

____

____

PHONE NUMBER FOR CONTACTING:____________________________

Figure 6. Personal Data Sheet

Underclass Students
College of Engineering
West Virginia University

1 May, 1957

Gentlemen:

This letter is concerned with your possible participation as volunteers in developing experimental data for my thesis. Your data will be analyzed for the purpose of evaluating training procedures. At this time I cannot inform you more fully as to the objectives without causing possibly a bias factor in the statistical analysis.

It is necessary that you volunteer with an interest in this problem, since learning cooperation is vital. In other words during the three sessions you will have to show the same interest that you would show in any class that you are taking; it will NOT require any outside preparation work. Three sessions are necessary: 1 hr. class lecture and note-taking; 1 hr. of training; 1 hr. of taking the actual data. It is impossible at this time to tell you which date your hour will occur, as it will have to be randomly chosen.

It is expected that the sessions will be held from 5:45 to 6:45 P. M. to enable attendance by everyone. These sessions will occur Monday through Friday the 13-17, and 20-24 May. The "bug" is that once you volunteer I will have to depend on your attendance for both the times and all the sessions; this is very important.

These sessions are of worthwhile value to all I. E. students. You will personally gain benefits from the training by becoming more proficient in timing work; this will give you an "edge" in coming courses.

There will be a short meeting Monday, 13 May, at 5:45 P. M. to fill out personal data forms in Room B-1, Engineering Building.

Your help and participation will be highly appreciated.

Very truly yours,

A. Bruckner, II
Instructor in Industrial Engineering
Room 147, Temporary Engineering Building

Figure 7. Letter Requesting Subjects

APPENDIX TWO

OUTLINE OF STAGE ONE LECTURE

OUTLINE OF STAGE ONE LECTURE

A. Development of Motivation and Perspective.

1. Time study is one of the important ways by which factories get number or quantity information about their men, machines, materials, or combinations of these. "You don't know anything about your subject unless you can tell me about it in numbers," says the president of one of the largest power companies.

   In our experiment we are going to become familiar with the use of the time study stopwatch, as we might use it in the simple tasks of measuring work--men, machines, or materials. From these standards of performance of various factory jobs, we get the necessary information for such functions as production control and scheduling, cost analyses of new methods and ways of doing things, incentive pay rates, and management control information.

   Don't kid yourselves--industry isn't run and managed by guesswork. It needs facts; facts need number information. <u>Our factories are run on the basis of this information</u>. Time study is just one valuable way of getting this information.

2. I don't want you to go home thinking that industrial engineering is solely time study--far from it. In fact, during two years of industrial practice, I did very little time study, whereas I did a lot of calculation, analyses, and recommendations based on time study data. Remember what we just said about factories being run on the basis of numerical information with which to do engineering work.

   Just because someone uses a slide rule, would you say that he was an engineer? An electrical engineer uses, say, a voltmeter to get some information. Is that all he does? A mechanical engineer uses drafting equipment for machine design work. Is a draftsman a mechanical engineer? An industrial engineer is just the same situation; he uses the stopwatch to help himself to do his job.[2]

3. The real difference between using a stopwatch versus some other measuring device is that the industrial engineer deals and works with people to get his information. Time studying requires high standards of responsibility.

   The rest of this topic dealt with the listing of the personal requirements and responsibilities in time study work.

B. Technical Information Topics.

1. Reasons for breaking a job into as small elements as can be conveniently timed. A discussion of the principles of time study element design.

2. Defining of raw time, normal time, and standard time.

3. Explaining endpoints and how to time elements. A simple example was given on how to use the observation sheet to record the endpoint times, and included a foreign element example. The continuous method was portrayed. The advantages and disadvantages of the two methods of timing were discussed.

4. Review of the decimal-minute stopwatch scale, and observer's position relative to the operator.

5. How to read the stopwatch: (1) keep the stopwatch, worker, and observation sheet in a straight line; (2) relax and get the rhythm of the job; (3) the dial hand moves quickly and you cannot read it like a stationary slide rule, so "grab" your reading. You will be less accurate trying to read it

---

[2]This was a first attempt made at an analogy to reduce some of the time study predjudices, and to give a better perspective of the role of the stopwatch in industrial engineering. An almost outstandingly good group response can be reported, including the non-industrial engineering students.

precisely than if you "grab at" or "snap" the reading. You will never be able to get a perfect reading, as the hand won't be there. Don't try to estimate whether it is 0.36 or 0.37; call it as you see it! Start your timing when you get the rhythm of the job. To summarize: relax and get the rhythm of the job to be timed; keep the watch, board, and worker in a nearly straight line; grab your reading or the dial hand will be well past the endpoint.

APPENDIX THREE

STAGE THREE OPERATION INFORMATION

Table 5. Time Study Element Description of Stage Three Assembly Operation

Element Number	Element Description
1	Right hand reach to bin number three and grasp stem, left hand reach to bin number two and grasp body and seat, move to assembly area and bring together, right hand position stem into body and seat, right hand release.
2	Right hand reach to bin number four and grasp bonnet, move and position bonnet over stem, screw onto acme thread on valve stem to reach body and seat threads, screw onto body and seat threads finger firm, right hand release.
3	Right hand reach to bin number five and grasp packing nut, move to stem and position, push-slide over stem, screw onto bonnet threads finger firm, right hand release.
4	Right hand reach to bin number six and grasp handle, move and position handle onto squared shank of stem, right hand release.
5	Right hand reach to bin number seven and grasp bolt, move and position bolt through handle into stem, screw in bolt finger firm, release right hand and drift to bin number three, left hand move to disposal box, left hand release.

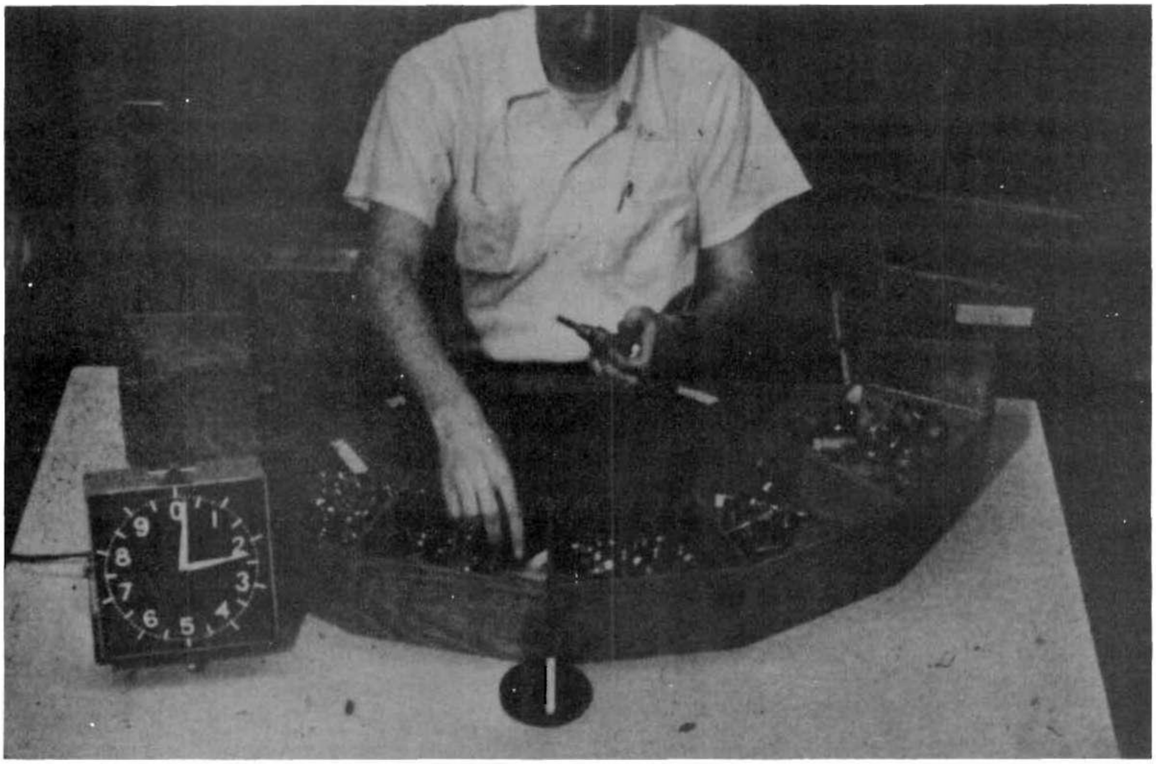

Figure 8. Workplace Layout of Stage Three Operation in Actual Use.

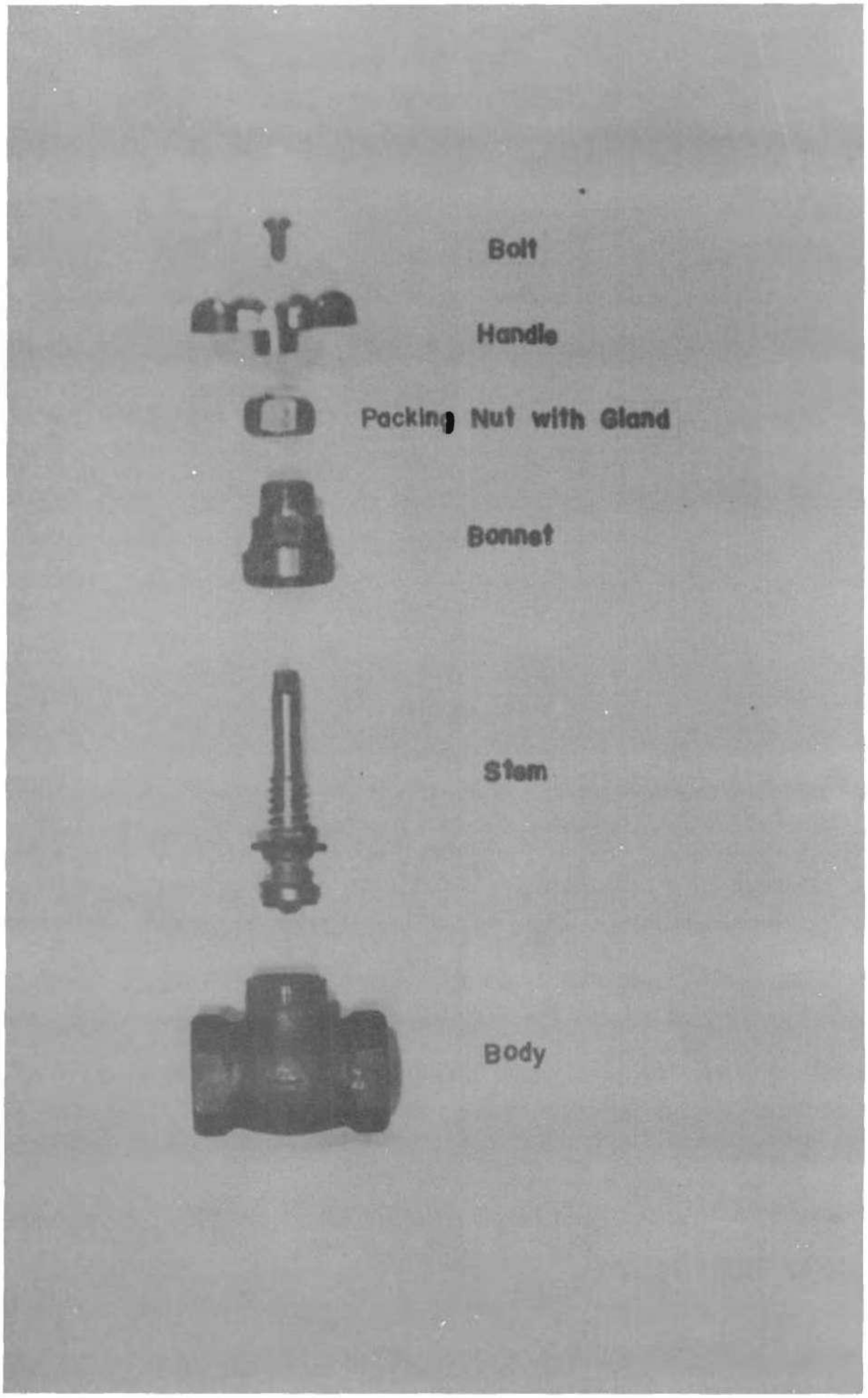

Figure 9. Exploded View of Three-quarter Inch Globe Valve Used in Stage Three Operation. Picture is approximately one-half true size.

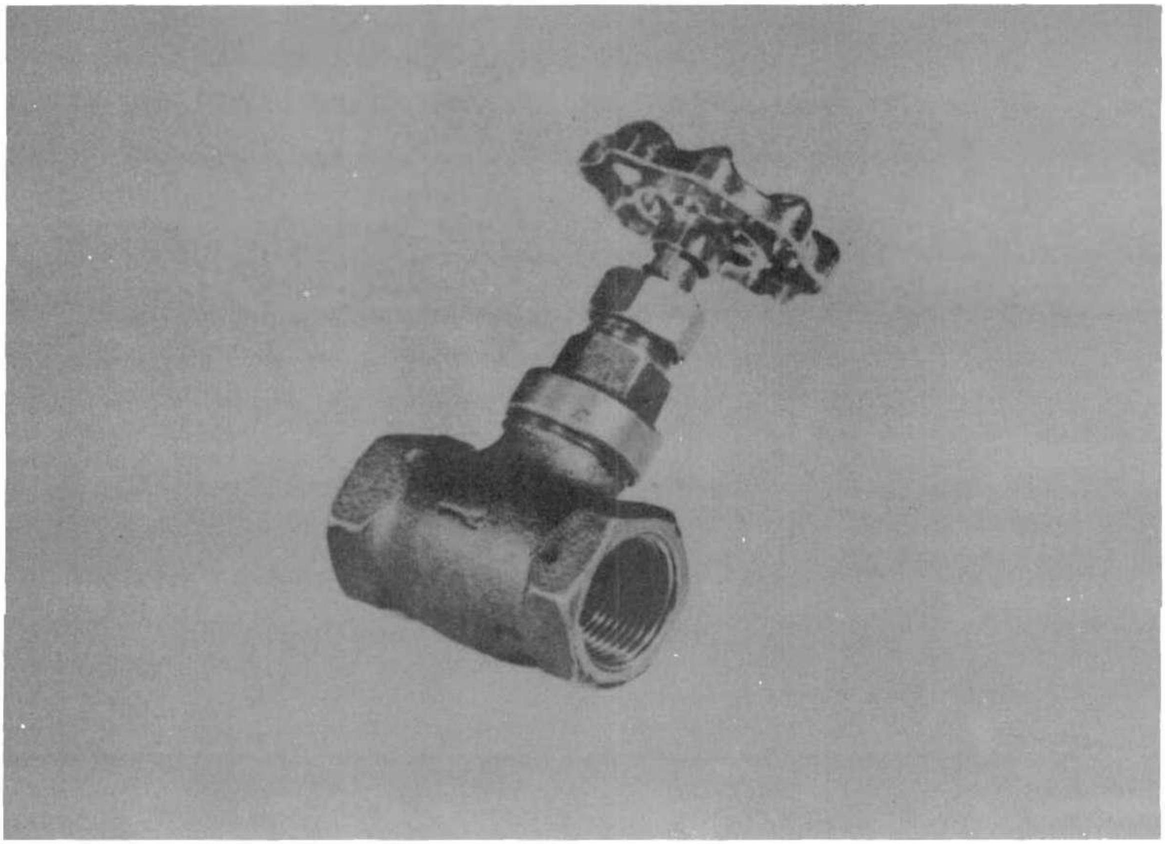

Figure 10. Assembled View of Three-quarter Inch Globe Valve Used in Stage Three Operation.

MASTER — MOTION PICTURE RECORD — MASTER

OPERATION NO. ____________ FILM NO. TxR 449
PERIOD NO. ____________ DATE 20-22 MAY TIME 6:20 PM
PART NO. STOP GLOBE VALVE BY J. VASOTI

CAMERA DATA:

CAMERA NAME BOLEX H-16 FILM 16mm TRI-X LENGTH 100 ft.
LENS NAME PAN-CINOR WESTON:
FOCAL LENGTH 20-22 DAY ____________
MAXIMUM f. LENGTH ____________ TUNG. ✓
CAMERA SPEED 16 FRAMES / SEC LIGHT READING 6.5
MOTOR DRIVE: YES ✓ NO ____ ON CENTER WORKPLACE
TYPE BOLEX PAILLARD (18 VOLTS) APERTURE f. 5.6
EXPOSURE METER WESSON FOCUS: 8 ft. 0-8 in.
MICROCHRONOMETER YES TO: CENTER WORKPLACE
PHOTOFLOODS:
Yes ✓

Scale: 1/4 in. = 1 ft.

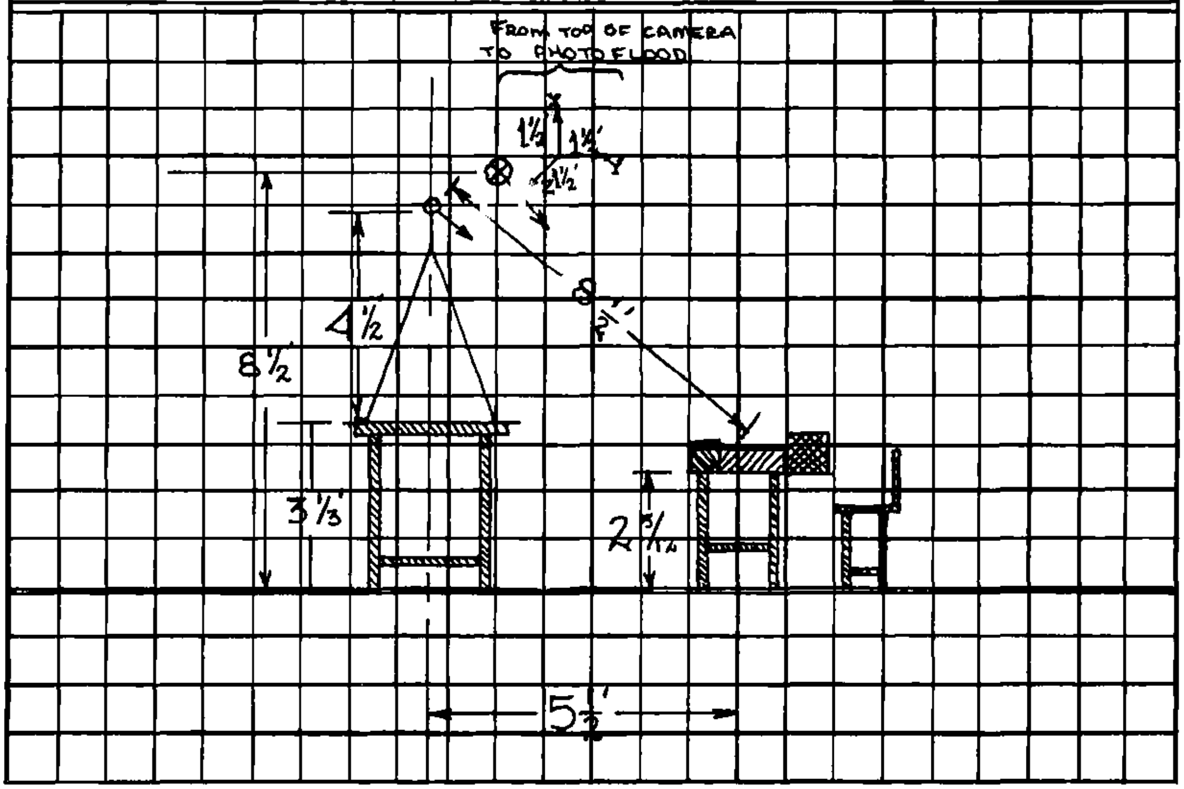

Figure 11. Master Micromotion Study Data Sheet.

APPENDIX FOUR

STATISTICAL ANALYSES

Table 6. Analysis of Variance Table for Bias

Source	Degrees of Freedom	Sum of Squares	Mean Squares	Expected Mean Squares
Total	129	972,602.90	--	--
Between Methods	1	51.73	51.73	$\sigma_e^2 + 5\sigma_S^2 + 65\sigma_M^2$
Between Elements	4	294,518.82	73,629.71	$\sigma_e^2 + 26\sigma_E^2$
Between Subjects Within a Method	24	127,131.98	5,297.17	$\sigma_e^2 + 5\sigma_S^2$
Method x Element Interaction	4	62,990.35	15,747.59	$\sigma_e^2 + 13\sigma_{ME}^2$
Residual	96	487,910.02	5,082.40	σ_e^2

Table 7. Analysis of Variance Table for Timing Variation

Source	Degrees of Freedom	Sum of Squares	Mean Squares	Expected Mean Squares
Total	128	10.8334	--	--
Between Methods	1	0.1400	0.1400	$\sigma_e^2 + 5\sigma_S^2 + 65\sigma_M^2$
Between Elements	4	1.1604	0.2901	$\sigma_e^2 + 26\sigma_E^2$
Between Subjects Within a Method	24	3.9955	0.1665	$\sigma_e^2 + 5\sigma_S^2$
Method x Element Interaction	4	0.3874	0.0969	$\sigma_e^2 + 13\sigma_{ME}^2$
Residual	95	5.1501	0.0542	σ_e^2

Table 8. Formulae of Sum of Squares for Bias and Timing Variation Analyses of Variance. For Timing Variation the Degrees of Freedom for the Residual and Total are Each Reduced by One

Factor	Degrees of Freedom	Formula of Sum of Squares
M	J-1=1	$\Sigma_j T^2_{.j.}/IK - T^2_{...}/IJK$
E	K-1=4	$\Sigma_k T^2_{..k}/IJ - T^2_{...}/IJK$
S	J(I-1)=24	$\Sigma_{ij} T^2_{ij.}/K - \Sigma_j T^2_{.j.}/IK$
M x E	(J-1)(K-1)=4	$\Sigma_{jk} T^2_{.jk}/I - \Sigma_j T^2_{.j.}/IK - \Sigma_k T^2_{..k}/IJ + T^2_{...}/IJK$
Residual	By difference	
Total	IJK-1=129	$\Sigma_{ijk} x^2_{ijk} - T^2_{...}/IJK$

Table 9. Formulae of Expected Mean Squares for Bias and Timing Variation Analyses of Variance

Factor	Model	Formula of Expected Mean Square
M	I	$\sigma_e^2 + K\sigma_S^2 + IK\sigma_M^2$
E	I	$\sigma_e^2 + IJ\sigma_E^2$
S	II	$\sigma_e^2 + K\sigma_S^2$
M x E	II	$\sigma_e^2 + I\sigma_{ME}^2$
Residual	II	σ_e^2

Table 10. Numbers of Missed and Recorded Readings and Chi-square Test (44)

Method	Missed Readings	Recorded Readings	Total Readings
I	a = 390	b = 1840	a + b = 2230
II	c = 311	d = 1919	c + d = 2230
Totals	a + c = 701	b + d = 3759	N = 4460

$$\chi^2 = \frac{(ad-bc)^2(N)}{(a+b)(b+d)(c+d)(a+c)}$$

$\chi^2 = 10.5633$ with one degree of freedom

Table 11. Bias and Timing Variation Coding Expressions for Analyses of Variance

$$x_i'\,_{\text{bias}} = (x_i)\,10^4$$

$$x_i'\,_{\text{timing variation}} = \log_{10}\left\{ (x_i + 0.000500)10^6 \right\}$$

Table 12. Original Data of Bias
Multiply values shown by 10^{-4} to obtain original values in minutes. Element letter symbols are lengths of elements in increasing order. Numbers in parentheses are the time study sequence.

Methods	Subjects	Elements A(4)	B(1)	C(3)	D(2)	E(5)
I	1	23	33	-41	32	46
	2	7	20	- 5	-12	12
	3	92	233	95	-114	34
	4	147	93	40	-35	-179
	5	9	155	79	-29	-97
	6	68	65	- 9	-50	-59
	7	69	61	- 9	-10	-98
	8	41	15	54	-22	-21
	9	43	381	35	-85	-74
	10	38	180	30	32	-49
	11	-17	155	63	-61	-34
	12	60	289	52	-110	-72
	13	11	82	13	-53	5
II	14	6	162	153	-65	19
	15	-89	-13	20	32	79
	16	97	240	43	263	68
	17	- 5	333	-73	-60	57
	18	-21	-22	-14	23	28
	19	-13	40	-51	- 2	21
	20	-29	23	- 8	- 6	8
	21	-47	108	28	-71	- 8
	22	23	73	110	12	-80
	23	66	-35	38	4	-87
	24	-53	101	- 6	- 8	40
	25	6	10	6	23	-22
	26	-15	127	91	-142	29

Table 13. Original Data of Timing Variation Multiply values shown by 10^{-6} to obtain original values in minutes. The value for the fifth subject and "E" element was treated as missing; the value shown is the calculated value discussed in Chapter IV. Element letter symbols are lengths of elements in increasing order. Numbers in parentheses are the time study sequence.

Methods	Subjects	Elements A(4)	B(1)	C(3)	D(2)	E(5)
I	1	124	134	79	111	191
	2	108	104	33	75	213
	3	550	5280	812	618	1845
	4	505	287	359	121	886
	5	55	1900	600	355	708
	6	235	169	127	530	448
	7	103	90	14	138	220
	8	463	413	222	618	396
	9	438	9900	184	-56	521
	10	40	12844	131	349	454
	11	109	2532	278	354	606
	12	243	1890	715	400	262
	13	480	76	47	93	1312
II	14	36	905	180	73	-411
	15	-20	514	456	450	264
	16	895	5682	517	18941	2745
	17	80	1933	286	453	224
	18	23	91	61	130	100
	19	54	265	364	678	272
	20	41	84	64	-38	24
	21	- 3	80	355	386	272
	22	221	628	1618	63	585
	23	264	213	474	-94	782
	24	269	268	150	128	950
	25	234	64	41	-16	113
	26	185	663	530	161	-72

BIBLIOGRAPHY

CITED REFERENCES

1. Barnette, Gasper Cisneros, Learning Through Seeing With Tachistoscopic Teaching Techniques, Dubuque, Iowa: W. C. Brown Company, Inc., 1951, p. 3.

2. Woodworth, Robert S. and Harold Schlosberg, Experimental Psychology-Revised, New York: Henry Holt and Co., 1954, p. 101.

3. Ibid., p. 90.

4. Barnette, op. cit., p. 2.

5. Woodworth, Robert S., Experimental Psychology, New York: Henry Holt and Co., 1950, p. 687.

6. Ibid., p. 688.

7. Ibid., p. 724.

8. Ibid., p. 591.

9. Anonymous, Night Vision Trainer, AF M 50-10, Washington, D.C.: Department of the Air Force, 1955, pp. 1-13.

10. Fountain, Paul, "Eyes That See", Flying, (August, 1945), pp. 30 ff.

11. Anonymous, "Split-Second Recognition . . . A New Allied Weapon", Aviation (July, 1943), pp. 119 ff.

12. Barnette, op. cit., pp. 39-64.

13. Wittels, D. G., "You're Not as Smart as You Could Be", Saturday Evening Post, 220 (April 17, April 24, May 1, 1948), pp. 20 ff., pp. 30 ff., pp. 30 ff.

14. Anonymous, "The Aviation Psychology Program in The Army Air Forces", Report Number One, Army Air Forces Aviation Psychology Program, Research Reports, edited by Flanagan, John C., Washington, D. C.: United States Government Printing Office (1948), pp. 177-181.

15. Renshaw, Samuel, "The Visual Perception and Reproduction of Forms by Tachistoscopic Methods", Journal of Psychology, 20 (1945), pp. 217-232.

16. Anonymous, "Split-Second Recognition", p. 385.

17. Renshaw, op. cit., pp. 222-224.

18. Fountain, op. cit., pp. 30 ff.

19. Barnette, op. cit., p. 115.

20. Ibid., p. 96.

21. Ibid., pp. 93-123.

22. Ibid., p. 34.

23. Morrow, Robert L., Motion Economy and Work Measurement, New York: Ronald Press Co., 1957, p. 233.

24. Ibid., pp. 231-236.

25. Barnette, op. cit., p. 67.

26. McFann, Howard H., John A. Hammes, and John E. Taylor, "Trainfire 1: A New Course in Basic Rifle Marksmanship", Technical Report 22, Human Research Unit Nr 3, CONARC, Fort Benning, Georgia, under the technical supervision of Human Resources Research Office, The George Washington University (operating under contract with The Department of the Army), October, 1955, p. 13.

27. Ibid., p. 11.

28. Loc. cit.

29. Eisenhart, Churchill, "The Assumption Underlying the Analysis of Variance", Biometrics, 3 (March, 1947), p. 4.

30. Scheffe', Henry, "Statistical Methods for Evaluation of Several Sets of Constants and Several Sources of Variability", Chemical Engineering Progress, 50 (April, 1954), p. 202.

31. Brownlee, K. A., Industrial Experimentation, Fourth Edition, London: Her Majesty's Stationery Office, 1949, p. 26.

32 Ibid., pp. 27-28.

33. Davies, Owen L., Statistical Methods in Research and Production, Edinburgh: Oliver and Boyd, 1949, Chap. 3.

34. Brownlee, op. cit., pp. 137-140.

35. Johnson, Palmer O., Statistical Methods in Research, New York: Prentice-Hall, Inc., 1949, p. 218.

36. Cochran, W. G., "Some Consequences When the Assumptions for the Analysis of Variance Are Not Satisfied", Biometrics, 3 (March, 1947), pp. 22 ff.

37. Bartlett, M. S., "The Use of Transformations", Biometrics, 3 (March, 1947), pp. 39 ff.

38. Barnette, op. cit., p. 67.

39. Plourd, Webster William, Aviation Clock Dial Characteristics in Relation to Speed and Accuracy of Reading, Unpublished M. S. Thesis, Georgia Institute of Technology, June, 1949.

40. Chapanis, A., W. R. Garner, and C. T. Morgan, Applied Experimental Psychology, Human Factor in Engineering Design, New York: John Wiley and Sons, Inc., 1949, Chap. 6.

41. Anonymous, "Split-Second Recognitions", p. 119.

42. Pierce, J. R., and J. E. Karlin, "Reading Rates and the Information Rate of a Human Channel", The Bell System Technical Journal, 36 (March, 1957), pp. 497-517.

43. Quastler, Henry, editor, Information Theory in Psychology, Glencoe, Illinois: The Free Press, 1955.

44. Brownlee, op. cit., pp. 43-45.

OTHER REFERENCES

Aveling, F., "The Perception of Tachistoscopically Exposed Symbols", British Journal of Psychology, 22 (January, 1932), pp. 193-199.

Bennett, Carl A., and Norman L. Franklin, Statistical Analysis in Chemistry and the Chemical Industry, New York; John Wiley and Sons Inc., 1954.

Causey, Oscar S., Exploring the Goals of College Reading Programs, Forth Worth, Texas: Texas Christian University Press, 1955.

Comrie, L. J. and H. O. Hartley, "Table of Lagrangian Coefficients for Harmonic Interpolation in Certain Tables of Percentage Points", Biometrika, 32 (1941-1942), pp. 183-186.

Fisher, R. A., Statistical Methods for Research Workers, sixth edition, Edinburgh: Oliver and Boyd, 1936.

Hald, A., Statistical Tables and Formulas, New York: John Wiley and Sons, Inc., 1952.

Hall, W. E., and J. R. Cushing, "The Relative Value of Three Methods of Presenting Learning Material", Journal of Psychology (July, 1947), pp. 57-62.

Harris, Albert J., How to Increase Reading Ability, New York: Longmans, Green and Co., 1953.

Hartley, H. O., "Methods of Interpolation", Biometrika, 32 (1941-1942), pp. 161-167.

Hicks, Charles R., "Fundamentals of Analysis of Variance", Industrial Quality Control, 13 (August, September, and October, 1956), pp. 17-20, pp. 5-8, pp. 13-16.

Hoban, Charles F., Jr., Encyclopedia of Educational Research, revised edition, Monroe, Walter Scott, New York: MacMillan Co., 1950, p. 85.

Kempthorne, Oscar, Design and Analysis of Experiments, New York: John Wiley and Sons, Inc., 1952.

Luckiesh, M., and F. Moss, Reading as a Visual Task, New York: Van Nostrand Co., 1942.

Merrington, M., and C. M. Thompson, "Tables of Percentage Points of the Inverted Beta (F) Distribution", Biometrika, 33 (1943-1946), pp. 73-88.

Mills, R. E., "Evaluation of Techniques for Teaching Word Recognition", Elementary School Journal 56 (January, 1956), pp. 221-225.

Mood, Alexander M., Introduction to the Theory of Statistics, New York: McGraw-Hill Book Co., 1950.

Moroney, M. J., Facts from Figures, Baltimore, Maryland: Penquin Books, Inc., 1953.

Oeser, O. A., "Some Experiments on the Abstraction of Form and Colour", British Journal of Psychology, 22 (January, 1932), pp. 200-215.

Osgood, Charles E., Method and Theory in Experimental Psychology, New York: Oxford University Press, 1953.

Snyder, A., "Flashreader in the Reading Laboratory", English Journal, 4 (May, 1952), pp. 269 ff.

Waugh, Albert E., Elements of Statistical Method, third edition, New York: McGraw-Hill Book Co., 1952.

Wedeen, S. U., "Mechanical Versus Non-Mechanical Reading Techniques for College Freshmen", School and Society, 79 (April, 1954), pp. 121-123.

Wooster, G. F., "Experimental Study of the Reading Rate Controller", Journal of Educational Psychology, 45 (November, 1954), pp. 421-426.

Wright, Peter, An Investigation of Methods and Positions Used in Manual Quality Picking of Small Objects, Unpublished M. S. Thesis, Georgia Institute of Technology, June, 1956.

Zimmer, Hans Richard, An Investigation of Hand Quality Picking of Small Objects, Unpublished M. S. Thesis, Georgia Institute of Technology, June, 1955.